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THESIS

A STUDY OF THE MEASURES OF EFFECTIVENESS FOR THE JMSDF AEGIS DESTROYER IN A LITTORAL, AIR DEFENSE ENVIRONMENT

by

Hideto Ito

December 1995

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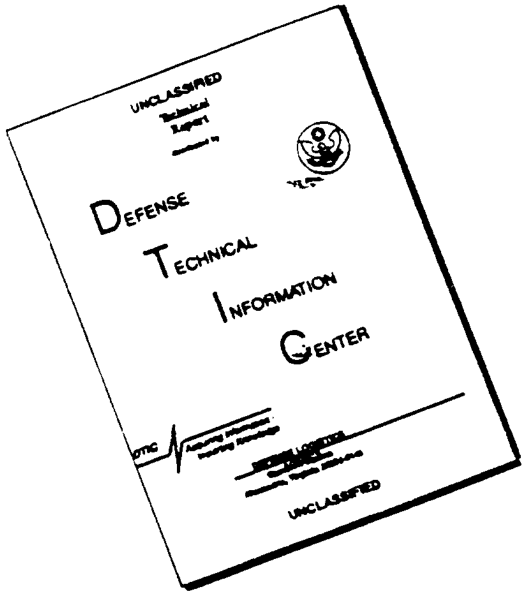

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Maritime operations in a littoral area demand a fundamental change in the future defense build-up of the Japanese Maritime Self Defense Force (JMSDF). The anti-air warfare (AAW) capability of the JMSDF in the littoral area, especially against very low altitude anti-ship cruise missiles (ASCMs), should be improved. To achieve the required future air defense lethality, the JMSDF must optimize the resource allocation within a limited budget. Therefore, it is important to understand the essential elements of air defense lethality by the JMSDF Aegis destroyer in order to improve their operational effectiveness. In this study, a measure of effectiveness (MOE) for Aegis lethality against an ASCM attack is defined as "a denial area at an acceptable risk." Using this MOE, spread sheet lethality models based on Aegis weapons characteristics, target detection range, reaction time, and ASCM speed, are developed and used to study several alternative improvements to Aegis.

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The reader is cautioned that computer programs developed in this thesis may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computation errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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I. INTRODUCTION

A. CHANGE OF THE WORLD ORDER ~ LITTORAL AREA OPERATION

Since the break up of the Soviet Union, there is a decreased chance of a conflict between the U.S. and the Soviet Union which could impact Japan. It is more likely that a conflict would arise with a third world country and would involve littoral areas. The end of the Cold War has caused changes in the tactical environment. It is expressed best by the change in naval strategies from "open ocean operations" to "littoral area operations". *From the Sea* states:

> The littoral region is frequently characterized by confined and congested water and air space occupied by friends, adversaries, and neutrals -- making identification profoundly difficult. This environment poses varying technical challenges to Naval forces. [Ref. 1: p. 3]

This indicates clearly that Japan needs to handle a more complex and uncertain battle space. It demands a fundamental change in future defense build-ups of the Japanese Maritime Self Defense Force (JMSDF) to meet the demands in a littoral area of operations.

1. Expected Mission of Japanese Fleet

Since Japan is a heavily sea-dependent country, there is no doubt that keeping the sea lanes of communication (SLOC) open for commercial maritime passage is a "lifeline" of Japan. Although the validity of SLOC protection is unchanging, the expected mission to achieve it is changing. The complex situation in the Asia-Pacific region, especially the future uncertainty of North Korea and China, and territorial disputes over the Spratly and Paracel Islands in the South China Sea, pose a more potential threat to Japan's SLOC than attacks from the ex-Soviet submarine fleets. Furthermore, as U.S. Department of Defense's Office of International Security Affairs points out:

> Japan's new global role involves greater Japanese contribution to regional and global stability. Japan is the world's largest Official Development Assistance provider and has increased its involvement in humanitarian and peacekeeping efforts around the globe, ... [Ref. 2: p. 10]

Therefore, Japan should anticipate playing a significant role in stabilizing the world security environment. This implies that the utilization of JMSDF assets for a wide range of missions, rather than the inherent SLOC protection, could be a realistic scenario in the near future. The Advisory Group on Defense Issues reported to the Japanese Prime Minister in 1993:

> We believe importance should be attached particularly to the capability of dealing with the following situations: interference in the safety of maritime traffic, violation of territorial air space, limited missile attack, illegal occupation of a part of the country, terrorist acts, and influx of armed refugees. [Ref. 3: p. 18]

It suggests that the JMSDF should seek to have multi-mission capabilities.

2. Necessity of AAW Capability Improvements for JMSDF

During the Cold War, the JMSDF focused on defending SLOC against Soviet submarine attack. It made JMSDF force structure slanted toward Anti-Submarine Warfare (ASW). With the changing tactical environment for super powers as well as Japan, several studies and articles devoted to the role of Japan and JMSDF in the last few years reported that:

> Shortfalls in the Japanese defensive arsenal continue to exist in sea lane defense - including airborne early warning and ship-borne anti-air capability. Deficiencies also exist in land based and ship-borne anti-missile capability. [Ref. 2: p. 26]

concluding:

> efforts should be made to build up a more balanced maritime defense capability. For example, the surveillance and patrol functions as well as anti-surface and anti-aircraft battle capabilities should be further improved.[Ref. 3: p. 22]

It is clear from these extracts that the JMSDF must concentrate on improving the anti-air warfare (AAW) capability to participate variety of future operations.

3. Necessity of COEA Approach for JMSDF

In the Post-Cold War era, "It is hardly likely that fiscal conditions surrounding defense buildup will improve in the long term." [Ref. 3: p. 19] Actually, Japanese Defense Agency's (JDA's) weapons procurement has fallen steadily from $12.33 billion in fiscal 1990 to the present $9.48 billion [Ref. 4: p. 23]. Therefore, the JMSDF must be cost-effective. To achieve the future defense demands, it must optimize the resource allocation with a limited defense budget in order to maintain and improve current defense capability.

As an example of the need for optimizing resource allocation, consider the next generation support fighter called FS-X. It is doubtful whether this fighter is cost-effective. As stated by *Aviation Weeks and Space Technology* :

> The JDA's 1996 budget request marks unit prices for FS-X at $126.8 million, including $14.4 million for spares. ... With a full production run, the JDA

expects unit costs to drop to the $82-83 million level. still a third more than initial estimates of about $55 million. [Ref. 5: p. 25]

Compared to other aircraft unit prices, for example, the F-14D at $88.1 million, F-15E $43.7 million, F/A-18E/F at $83.2 million, [Ref. 6] MIG-29 at $27 million [Ref. 7: p. 26], and the Su-32FN at $36 million [Ref. 7: p. 25], the FS-X looks too expensive. Even though this cost should be seen as a so-called opportunity cost rather than just aircraft price, it is still open to question whether a sufficient study of the cost effectiveness of the FS-X had been done in the early stage of this program.

A Cost and Operational Effectiveness Analysis (COEA) is a fundamental task of weapon system acquisition in the U.S. According to *DoD Instruction 5000.2*, one of the intentions of COEA is to:

> Aid Decisionmaking by illuminating the relative advantages and disadvantages of the alternatives being considered and showing the sensitivity of each alternative to possible changes in key assumptions (e.g., the threat) or variables (e.g., selected performance capabilities). [Ref. 8: 4-E-1]

The COEA is one of the essential elements of the U.S. DoD decision making process for all acquisition programs, especially under a shrinking budget. Improving the current weapon acquisition system by using the COEA approach is vital to the Japanese Defense Agency.

B. PURPOSE

This thesis will develop a recommendation, based on a COEA approach, for sea-based anti-air defense (AD) systems. It will focus on improving the JMSDF fleet AAW or AD capability. It will use a COEA logic basis to develop and identify the essential elements and events in an AD scenario to provide the prerequisites of a JMSDF Fleet AAW capability improvement program. It could be said that it is a kind of Essential Elements Analysis (EEA). In terms of COEA, *DoD Instructions 5000.2* says that:

> A cost and operational effectiveness analysis will typically draw on several sub-analyses. These include analyses of mission needs, the threat and U.S. capabilities, the interrelationship of systems, the contribution of multi-role systems, measures of effectiveness, costs, and cost-effectiveness comparisons. [Ref. 8: 4E-2]

Although the highlight of COEA is "cost-effectiveness comparisons", this thesis will limit the discussion to the operational effectiveness known as military utility, since reasonable cost data is not available. In short, the goals of this thesis can be summarized as follows:

1) Define an measure of effectiveness (MOE) for AAW operations.

2) Illustrate spread sheet models measuring the JMSDF Aegis destroyer AAW operational effectiveness.
3) Identify current JMSDF system deficiencies and essential factors.
4) Propose some desirable AAW assets options for JMSDF.

C. FRAMEWORK OF RESEARCH

This thesis has been organized into four areas (Chapters II through V).

Chapter II analyzes the expected mission of the JMSDF subjectively and represents it by characterized parameters. It then surveys the current and near future predicted threats and AAW improvement programs.

Chapter III develops spread sheet models to measure operational effectiveness of the characterized mission discussed in Chapter II. Two models are presented: The expected value model and a Monte Carlo simulation.

Chapter IV shows example results from these models. It examines the current system deficiencies and proposes methods for satisfying the JMSDF requirements and alleviating deficiencies.

Chapter V presents the recommended development of new AAW assets based on the analyses in Chapter II through Chapter IV.

Chapter VI summarizes conclusions and presents remaining problems.

II. MISSION THREAT ANALYSIS

A. THE MISSION ENVIRONMENT FOR THE JMSDF AEGIS

The expected missions of the Japanese fleet are expanding. Reflection on some of these missions reveals the possibility that support from the Japanese Air Defense Force (JASDF) could be low. In the past, JASDF assets, such as the F-15, FS-X, E-2C, and AWACS were procured and deployed on the assumption that their required mission capabilities were to prevent the invasion of Japanese territory. These aircraft are all land-based. Their mission range and endurance, with the exception of the Airborne Warning and Control System (AWACS) aircraft, are designed for territorial operation. Unfortunately, AWACS is not flexible because only a high intensity situation would permit its use beyond Japan's territorial boundaries. Although we should not ignore the U.S. Pacific Fleet and the Japan-U.S. Security Treaty, we cannot assume that the JMSDF will always be supported by U.S. Forces. It is certainly the most desirable situation, but we should not be too optimistic.

Furthermore, as Mashiko [Ref. 9] pointed out, the two most likely crisis scenarios to occur around Japan in the early 21st century are "the repercussion from other regional conflicts" and "the participation in peace-keeping operations (PKOs)". Both of these scenarios belong to the category of a low-intensity conflict (LIC). In this type of conflict, "the use of military force is highly focused and restrained, often relying more on police, propaganda, intelligence, and military support elements than on military combat units." [Ref. 10: p. 166] This implies that limited military assets, like surface action groups (SAGs), maritime action groups (MAGs), or less capable force groups, could be projected in the beginning of a conflict. However these conflicts could escalate rapidly, or a sudden attack may happen, even though the conflicts seems under control. The biggest concern would be the proliferation of sophisticated weapons, especially anti-ship cruise missiles (ASCMs).

Another mission which has become important is Theater Ballistic Missile Defense (TBMD). According to *Jane's Defence Weekly* [Ref. 11: p. 21], the U.S. Ballistic Missile Defense Organization (BMDO) briefed Japanese officials on the four basic defense options for early in the next decade to counter the perceived threat of a North Korean ballistic missile attack on the Japanese home islands. Their options are summarized below:

1) Four existing and currently planned Aegis destroyers for upper tier defense, and twenty four Patriot PAC-2 batteries, which will become operational in 1999 and upgraded to PAC-3 standards for lower tier defense. This would only account for an attack by the North Korean Nodong-1 intermediate range system, and it would divert Aegis from protecting the SLOC. This option would cost $4.5 billion.
2) An additional eight Aegis destroyers, with the Patriot batteries the same as in option 1, and a new surveillance radar system that would be located west of Tokyo. This is the most flexible option, but the cost would be $16.3 billion.
3) Six land-based Theater High Altitude Air Defense (THAAD) systems, and the twenty four upgraded Patriot PAC-3 batteries. The missile inventory would be 560 missiles. This option would cost $4.55 billion.
4) Four Aegis ships, twenty four PAC-3 Patriot batteries, and six THAAD systems. This option would cost $8.9 billion.

In terms of the Aegis destroyers, these options are based on the assumption of a new theater missile defense system and 36 anti-theater ballistic missiles. In short, it could be said that this improvement expands the Aegis high altitude threat handling capability. However, it does not appear that the new system would improve our Aegis low altitude thrreat handling capability.

Is a ballistic missile attack really likely to occur? W. Seth Carus [Ref. 12: p. 31] provides some thoughts on this subject:

> The Persian Gulf war is certain to affect the attitudes of Third World countries concerning the relative value of ballistic missiles as compared with cruise missiles. Military experts in the Third World were acutely aware of the dramatic contrast between the inaccuracy of the Iraqi Al-Husayn ballistic missiles and performance of the U.S. tomahawk missiles.

Therefore, this thesis will focus on the low altitude threat which seems to have received less attention in Japan than TBMD. However, It is still important to keep TBMD aspects in mind as we examine any AAW improvements. Even if we examine the low altitude threat, the contribution to TBMD, or the expansion of the high altitude mission, should be given consideration.

B. PRIMARY FUNCTIONS OF JMSDF AEGIS

There are a variety of missions for Aegis. Usually, own-ship survivability is a common evaluation value in terms of AD at sea. Seeking own-ship survival during a given

mission is one of the most important aspects, since it is and has been a prerequisite for achieving any of the missions, except the KAMIKAZE attacks in WWII. However, it is not enough since it does not guarantee the success of any mission. In other words, own-ship survivability is a necessary condition, but not a sufficient condition by itself for mission success. Relevant to this point is Ball's [Ref. 13] following summary of the primary air defense missions:

1) the protection of high value assets
2) the protection of maneuver forces
3) the selective disruption or destruction of specific aircraft

What is immediately apparent in this extract is that the main objective of an AD unit is not to survive itself, but to provide or secure air space against hostile air activity. From this view point, the principal function of Aegis is obviously to defend a space as large as possible.

The current primary air threat to the JMSDF is an anti-ship cruise missile (ASCMs). The next section will examine this threat.

C. PREDICTED THREAT ~ ANTI-SHIP CRUISE MISSILE (ASCM)

> Two of the most difficult targets for AD today are the cruise missiles that approach at either a very low altitude or a very steep angle at very high speed and the hovering helicopter that is difficult to detect because of back ground clutter. [Ref. 13]

> Today, the principal threat to ships at sea - the anti-ship cruise missile - flies lower, faster, and with less radar cross section than its predecessors. [Ref. 14: p. 37]

This thesis will focus on the very low altitude incoming ASCM, or so-called sea-skimmer, since it is one of the most difficult targets which we could face. For the moment, it is useful to examine the features of current low-flying ASCMs.

Characteristic data of major ASCMs are listed in Appendix A. The general features of current low-flying ASCMs are subsonic (Mach 0.8 ~ 0.93), active radar homing, and less than 100 NM maximum range (most are less than 50 NM). It is noted that the Soviet and Soviet-derived ASCMs which have been the primary threat during the Cold War, are unlikely to be sea-skimmers except for the SS-N-25 "Harpoonski" and the P-270 "Moskit". It could be said that typical sea-skimming ASCMs belong to the Exocet family since their abilities are ranked high and they are widely used. The most advanced version is

the Exocet Block II. It is still a subsonic missile, but a company manager said in Aviation Week & Space Technology that:

> application of digital technology permits an optimized sea-skimming flight profile through calculations of the lowest possible altitude based on the actual sea state condition. The Block II weapon is able to fly at altitudes of only several meters above the water.[Ref. 15: p. 66]

According to *World Naval Weapon Systems* [Ref. 16], the Exocet Block II's capabilities are further explained:

> The missile can corkscrew to evade terminal defenses. It can also dogleg, changing direction by up to 90 deg. It can fly a self-adapting sea-skimming profile in sea states up to 7, and it has better ECCM. The range, about 70 km, is not affected. The missile can select targets (i.e., it has some form of target identifier on board). A new FCS, ITL/ITS 70, allows multiple targets to be engaged, fires salvos against more than one target and converging salvo on one target. [Ref. 17: p. 21]

These extracts imply that if an AD system fails to shoot the Exocet down within the missile defense zone, it is almost impossible to achieve a "hard kill". Future ASCM improvements could be demonstrated by the Anti Nacires Supersonique (ANS), which is intended to reach supersonic speed (Mach 2.0) [Ref. 16: p. 174] . Its range will be 55 NM in lo-lo-lo profile, or 110-137 NM in lo-hi-lo or hi-hi-lo profile. The maneuverability limit is 15G (compared to 6G for Exocet).[Ref. 17: p. 21]

P-270 Moskit is another illustration of a supersonic sea-skimmer. It may fly at Mach 3.5, 23 feet above sea level, use an imaging microwave radar seeker, and be highly resistant to all but the most sophisticated countermeasures [Ref. 18: p. 47]. *Journal of Electronic Defense* [Ref. 19: p. 18] reported a possible transfer of Moskit missile technology to the People's Republic of China.

Friedman's comments on such a supersonic sea-skimmer include:

> The attraction of supersonic flight is that it drastically shortens time available to the defense. Moreover, even if a missile is hit, its fragments will continue towards the target. The faster the missile, the more momentum in the fragments and the greater the minimum acceptable destruction range. On the other hand, it is probably quite difficult to make a sea-skimming supersonic missile, because the momentum will also reduce its ability to pitch up in time to miss oncoming waves. The missile itself may be quite hot (from aerodynamic heating) and thus it may be more susceptible to early IR detection. [Ref. 20: p. 43]

These ASCMs shrink the reaction time by not only hiding themselves by the curvature of the earth but also pushing out the inside minimum effective intercept zone. A commonly accepted rule of thumb is that the danger zone represented by the effect of shot-down missile wreckage is about 1 km per Mach number of missile speed [Ref. 18: p. 47]. The available time and room for error left to shipboard decision makers is small. Figure 1 helps

us get a sense of the available time from initial ASCM detection to the launching of a surface-to- air missile (SAM). Suppose a SAM must intercept an ASCM at 5 NM from the launching ship with an average SAM horizontal speed of Mach 2.0. An initial detection range is radar horizon, Rh, which is given by: [Ref. 21: p. 244]

$$Rh = 1.23 \cdot (\sqrt{h_{RADAR}} + \sqrt{h_{ASCM}}) \qquad (NM) \qquad (2.1)$$

where h_{RADAR} is a radar height (feet) and h_{ASCM} is an incoming ASCM flight altitude (feet). The Aegis radar height of 55 feet, and the cruise altitude of an incoming ASCM, with the ASCM coming straight in with a constant speed are also assumed.

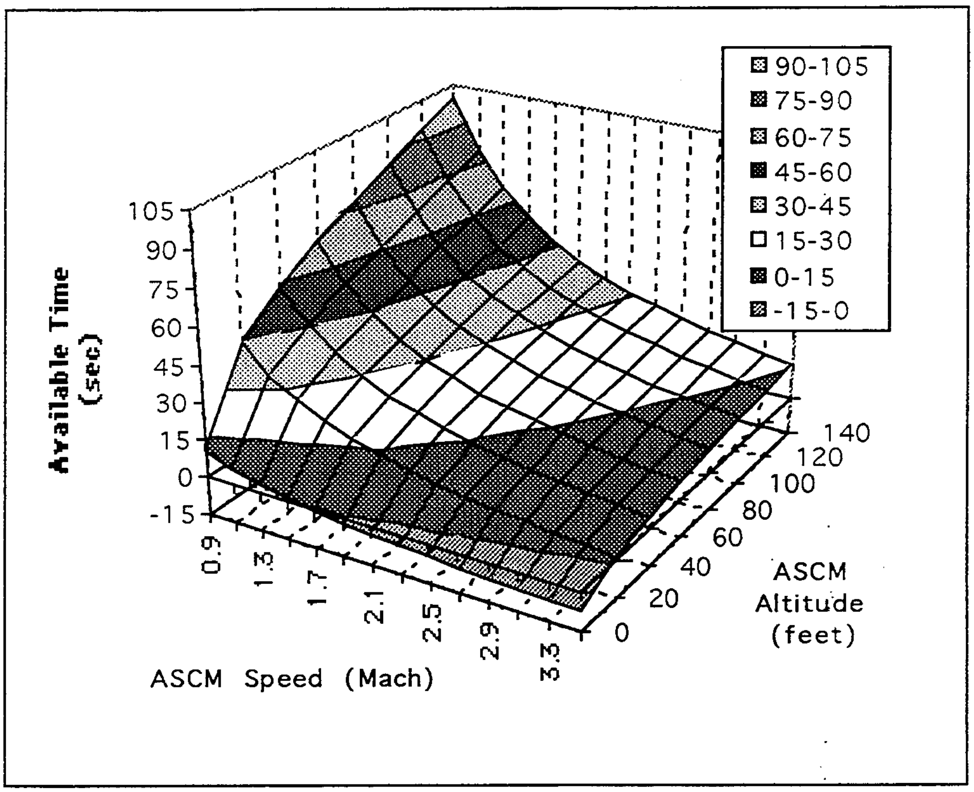

Fig. 1 Available Time for Intercept at 5 NM
(SAM Average Speed: Mach 2.0, Radar Height: 55 feet)

For example, if an ASCM is approaching at a 100 foot altitude at Mach 0.9, about 90 seconds are available for launching a SAM. If an ASCM is flying lower, say 40 feet, the reaction time goes down to about 60 seconds. Furthermore, if it flies supersonic, Mach

2.0, less than 20 seconds are available. In the case of Mach 3.5, only 5 seconds are left. To make matters worse, when a friendly surface unit (FSU) is stationed at 10 NM from Aegis, a SAM launched from Aegis should intercept an ASCM at more than 10 NM away. The available reaction time against Mach 0.9 ASCM is at most 14 seconds. If the speed of an ASCM exceeds Mach 1.4, no time is available for Aegis. However, these are, in a sense, optimistic estimations since it is doubtful that a detection will be made at the radar horizon. The biggest trend in ASCM improvements is to reduce observability:

> One avenue being pursued is to enhance the "stealth" characteristics of the missile. This could be achieved by optimized airframe shaping and the incorporation of radar absorbent material (RAM) in the skin to reduce the missile's radar cross section (RCS). ... In addition, advanced propulsion, such as propfans, has been studied as a means of reducing the weapon's infra-red signature. [Ref. 22: p. 154]

The simple form of the radar equation that expresses the maximum radar range, Rmax, is given by: [Ref. 23: p. 15]

$$R\max = \left[\frac{Pt \cdot G \cdot Ae \cdot \sigma}{(4\pi)^2 \cdot Smin}\right]^{\frac{1}{4}} \qquad (2.2)$$

where Pt is the transmitted power (watts), G is antenna gain, Ae is antenna effective aperture (m^2), Smin is minimum detectable signal (watts), and σ is radar cross section (RCS) (m^2). If a given radar is specified, all parameters except RCS are constant in this equation. The maximum detection range varies with the fourth root of RCS. If the RCS is reduced by a factor of 10, then Rmax is shortened by a factor to 0.56. In other words, suppose Aegis can detect a target, which has $1m^2$ RCS, at 100 NM range. If the RCS of the target goes down to $0.1m^2$, the possible detection range of Aegis should be shortened to 56 NM.

The above discussion implies that the earliest warning the ship may receive is the radar seeker emission of the ASCM rather than the radar detection. However, although active radar seekers are the most common terminal guidance device, IR seekers and thermal imaging are in service, and dual-mode seekers that incorporate both active radar and passive IR advantages are emerging technology. This deprives AD systems of early alert by Electronic Support Measures (ESM). Besides,

> Such seekers have the advantage of being effective in a crowded environment and, if coupled with feed-back data link, could allow the selection of the desired target or the most appropriate aim-point. [Ref. 22: p. 154]

With highly complex evasive maneuvers, low observability, and a limited amount of time, it is clear that it is difficult to kill sea-skimming ASCMs. As applied to the littoral area:

> Even a small business jet could be turned into a cruise missile with five tons of high explosives, a television camera for takeoff, autopilot, GPS and a cheap navigation system. [Ref. 24: p. 46]

> Every recent conflict involving air power has confirmed that the present methods of distinguishing friendly forces from others are inadequate. The IFF (identification, friendly or foe) systems now in service are unreliable, vulnerable to electronic warfare, and can positively identify friendly platforms only. [Ref. 25: p. 334]

The threat of a sudden attack from an "unknown" target in littoral area operations is of more concern due to a greater variety of delivery platforms and unreliable IFF capabilities. Probably the most difficult problem for ship commanders is the confirmation of the intention of an "unknown" contact.

D. AAW IMPROVEMENT PROGRAMS

It is useful to survey the trend of the sea-based AAW improvement programs to understand the general ideas and available technology. Probably the best program for trend analysis for JMSDF Aegis destroyers is the USN DDG-51 Flight IIA upgrade program, since DDG-51 Arleigh Burke is the base model ship of JMSDF Aegis destroyers. This program incorporates littoral area operations. Based on *Jane's Fighting Ship 1995-1996* [Ref. 26] and *U.S. Institute Proceedings/July 1994* [Ref. 14], the scheduled modifications of the DDG-51 in terms of AAW are summarized in Table 1.

Adding Systems	Deleting Systems
* Six more VLS cells (32 forward, 64 aft.) * Evolved Sea Sparrow CIWS * Dual hangar, Two SH-60s * Tactical Data Information Link (TADIL J) * Raising the position of aft SPY 1-D arrays	* Harpoon * Pharanx CIWS (after ESSM addition)

Table 1. DDG-51 Flight IIA Upgrade

From this upgrade program, three trends become clear. First, a short range missile is used as a point defense hard kill weapon instead of guns such as the Phalanx and the Goalkeeper. This must be based on the doubt about the effectiveness of current close-in weapon systems (CIWS) against ASCMs with high speed and maneuverability.

> Reportedly the Exocet tests convinced the French navy that close-in gun systems were futile. The British reached similar conclusions based on the expectation that future anti-ship missiles would be hypersonic.[Ref. 17: p. 132]

A couple of short range SAM improvements such as Rolling Airframe Missile (RAM or RIM-116A), Evolved Sea Sparrow Missile (ESSM or RIM-7R), and ASTER exist. These support a trend away from Phalanx and Goalkeeper. These three missiles' features are summarized in Table. 2 based on reference [16] and [17].

ESSM	RAM (U.S., German, Danish)	ASTER (France)
* Range 4-10 NM *Speed Mach 4.0 *Guidance semiactive midcourse, IR terminal, and anti-radar homing	*Potential Target Active homing missiles (RAM II can use IR seeker for search against IR or semiactive missiles) *Range 5 NM *Speed Mach 2.0+ *Guidance Passive RF midcourse, IR terminal	*Potential Target Sea-skimmers (Mach 2.5, 15-Gs) Anti-radar missile Fighter aircraft *Range 10 km : supersonic target 15-17 km: subsonic *Reaction Time 15-20 sec. 5sec.(using Arabel radar)

Table 2. Short Range SAM

Another approach for improving the point defense capability for ships is using "soft kill" weapons. These options include active off-board decoys or off-board expendable jammers such as Nulka. The Nulka was intended to overcome the weakness of jammers against anti-radar or home on-jam type missiles.

> Jammers present the same hazards in operation as do the radar systems they counter - their emission can be detected by passive means from ranges considerably greater than the effective range of the system in question. Just as a ship using its radar reveals its position, so does any ship initiating active jamming procedures. This is vulnerable to exploitation by anti-radar missiles (ARM) used in the home-on-jam mode. [Ref. 27: p. 42]

When the Nulka system is launched, a hovering rocket called Winnin carries an active jammer to suppress the threat. It looks like Chaff, but there are no Chaff-like deficiencies. That is:

> Chaff has a limited ability to mimic radar cross sections, is affected by wind, rain and mist, and limits the maneuverability of the parent ship [Ref. 28: p. 59]

The features of Nulka are summarized below:

> The core of the Nulka system is a hovering rocket decoy with a programmable trajectory. The decoy is launched from the ship to be protected and hovers for up to two minutes. The programmable trajectory allows selection of the optimum flight path for seduction of incoming missile. The decoy can move at ship-like speed, so the incoming missile cannot discriminate on a 'motion' bias. The Nulka decoy has an all-weather capability, its hovering system prevents the wind shifting the decoy's position, and it is fired automatically.[Ref. 28: p. 60]

The Nulka decoy seems like an attractive way to provide for own-ship defense. When considering these point defense weapons, it is necessary to examine both "hard kill" and "soft kill", and to compare the effectiveness and suitability based on a specific threat.

Secondly, carrying a large complement of missiles could sustain a ship through a longer operation. Adding six more cells to the vertical launching system (VLS) could achieve this. Adding to that, using helicopter launched anti-ship missiles (ASMs) such as Penguin and Hellfire instead of using Harpoon against small boats, may result in increasing the missile quantity. It may be worth pointing out that the Mk-41 VLS can carry four Sea Sparrows in a single cell. Moreover, *World Naval Weapon Systems* [Ref. 16: p. 441] reports:

> At the 1990 U.S. Navy League show, FMC, the manufacturer, displayed a cell holding two slightly slimmed SM-series missiles (arranged diagonally), which were described as a General Dynamics proposal for a possible follow-on to the current SM-2(MR) for the mid-1990s.

These combinations of missiles result in not only increasing the total amount of missiles but also concealing actual numbers of missiles being carried.

Thirdly, using airborne assets could extend the surveillance space and over-the-horizon (OTH) capability. By utilizing a higher radar position, the surveillance horizon is extended. Two SH-60s are key for OTH operations.

> The most significant Flight IIA upgrade is the addition of a dual helicopter hangar designed to accommodate two SH-60Bs as well as to land, refuel, and rearm a variety of helicopters including Army AHIPs (OH-58D), Cobras (AH-1), H-46s, and Comanches (RAH-66). The addition of a hangar is paralleled by a separate acquisition program to equip the SH-60B with Penguin and Hellfire missiles, laser target designator, and forward looking infrared (FLIR)

sensor. The helicopters will contribute immeasurably to the ship's surveillance and identification capability, and also provide an over-the-horizon detect-and-engage capability, which is particularly important against the fast patrol boats and diesel submarines common to littoral countries worldwide. [Ref. 14: p. 38]

This idea of using helicopters armed with ASMs could be adopted based on the successful experiences of the Gulf War in 1991.

> British Aerospace Sea Skua anti-ship missiles fired from Royal Navy Lynx helicopters engaged 19 Iraqi patrol boats and other craft, sinking four and disabling the other 15. [Ref. 29: p. 48]

Another way to extend the possible ASCM detection range is by putting passive sensors on ships. Passive sensors include not only traditional ESM, but also electro-optical (EO) sensors such as forward looking infrared (FLIR) sensors, TV sensors, and laser range finders. Actually, these sensors are in service.

> US Navy has fielded airborne EO sensors on its carrier-based Intruder A-6Es, Tomcat F-14A/Ds, and Hornet F/A-18C/Ds, it has only deployed a handful of shipboard EO sensors, most on board frigates and destroyers tasked with the tanker escort mission during the Iran-Iraq War and in Operation 'Desert Shield/Desert Storm'. [Ref. 30: p. 28]

ESM can detect a target over the horizon. Even though they provide only direction (bearing and elevation) of targets, early warnings increase reaction time for ship commanders and also assist in the detection by radar. The reasoning is supported by the following:

> At the very least, the data available can be used to eliminate areas of no interest so that active sensors can concentrate their searches on more productive sectors. The shift from all-around to quadrant search greatly increases the probability of being able to use radars without being detected; a case where the integration of electronic warfare input is of direct benefit to other sensor technology. [Ref. 27: p. 41]

It is not fair to ignore the "communications intercepts" by passive sensors for targeting. They can provide relatively accurate range estimates "by measuring the difference in arrival times between the ground wave and the skywave." [Ref. 27: p. 43] One such system is the SSQ-72, commonly called Classic Outboard. The new Outboard II or "SSQ-108(V)2 does away with the need to measure the arrival time of the ground wave and can use single-point measurement for determining range." [Ref. 27: p. 44] These sensors increase the efficiency of "active homing" missiles which can be programmed to turn on their seeker closer to the target. However, it is doubtful that communications intercepts by passive sensors will help friendly forces neutralize ASCMs or localize hostile platforms in a crowded littoral region. In the case where these devices are used by both Aegis and enemy platforms, the need for identification friend or foe (IFF) for weapons release is of more concern for Aegis ships, and consequently of great benefit to hostile forces.

Another advantage of passive sensors is undetactability. It is useful during tanker escort type missions. If the operation is under emission control (EMCON), only passive sensors can obtain valuable information. Furthermore, there are no multipath or ducting problems in IR. The typical Infrared Search and Track (IRST) devices are the French Vampir (DIBV 10) developed by SAT manufacturer.

However, the most important thing is fusing information from those sensors and providing useful tactical data to the ship commander rather than just improving each sensor's abilities. NTDS is a tactical data-handling system or combat-direction system (CDS) which has the function to coordinate information available on ships. However, it integrates only active sensors and "hard kill" weapons.

> The current NTDS installation drives hard-kill weapons, such as the NATO Sea Sparrow and the 5-inch guns, in a reasonably timely fashion, but there is no corresponding automated control of ESM decoys. ... NTDS ties together the ship's main active sensors but does not really embrace the passive ones. [Ref. 16: p. 353]

Additionally there is a new series of integrated systems. The Ship Self-Defense System (SSDS) is developing under a Quick-Reaction Combat Capability (QRCC) program.

> Mk 0 is RAIDS, which integrates sensors and artificial-intelligence processor (analogous to the Aegis C&D processor) to provide tactical advice on using weapons and countermeasures (it is not connected directly to any of them). The near-term SSDS Mk 1 connects SPS-49, an IRST, SLQ-32, RAM, and Phalanx. The mid-term SSDS Mk 2 adds the NATO Sea Sparrow Missile System and its TAS Mk 32, and is integrated with a ship's CDS. The far-term SSDS Mk 3 will use a new multifunction radar (MFR), the next-generation ECM system (AIEWS), and a new missile (either ESSM or an SDIO-derived weapon), and will be compatible with the cooperative engagement concept (CEC). [Ref. 17: p. 37]

Furthermore, Battle Group AAW Coordination (BGAAWC), Force AAW Coordinating Technology (FACT), and Cooperative Engagement Capability (CEC) are working to expanding the tactical data integration from single ship to the battle group.

> The goal is to devise effective means to integrate all forms of tactical data, sensors and weapons employed by a multi-ship naval force into a single, distributed AAW weapon system.[Ref. 30: p. 34]

It could be analogous to the computer work station. CEC is explained in reference [17: p. 39] as follows:

> CEC is cooperative engagement capability, to be achieved through a data-distribution system (DDS) linking cooperative engagement processors (CEPs). In effect, the jam-resistant DDS is the next step beyond Link 11/16, and CEP is the step beyond CDS. CEC needs a very high computing capacity to provide precise gridlock (to allow full use of all sensors within a battle group) and actual fire control (including the decision as to which weapon is to engage a particular target). The CEP distributed processor will cue on-board sensors or engage targets without any on-board sensor tracks. This is a new start scheduled for FY94, building on BGAAWC and FACT.

In terms of Aegis:

> Aegis ships are now participating in developmental and operational testing of the Joint Tactical Information Distribution Systems (JTIDS) with Navy E-2C Hawkeye airborne early warning aircraft and F-14 Tomcat fighters, Air Force, and other service players. A fully integrated Link 16/JTIDS system will be incorporated in the Flight II Arleigh Burkes in fiscal years 1996-97. [Ref. 31: p. 51]

Through the U.S. DDG-51 Flight IIA upgrade program discussion and the related literature survey, the outline of the current AAW technologies and the courses of improvements are clear. The four mainpoints of this discussion can be summarized as follows :

1) CIWS has to be improved against the emerging ASCMs by using improved short range SAMs and "soft kill" weapons.
2) More weapons carried by each unit at sea improve overall response capabilities. The key is the combination of missiles to perform operations more efficiently.
3) OTH sensor capability is required. This encompasses two aspects, an extended sensor envelope and an extended weapons envelope.
4) Integration of tactical data should be the backbone of AAW in the future.

III. METHODOLOGY FOR EFFECTIVENESS EVALUATION

A. AD WEAPON SYSTEM CHARACTERIZATION AND BASIC MODEL

1. Weapon Lethality

According to Ball [Ref. 13], the definition of weapon lethality is its ability to encounter, engage, and kill a target. These sequential events are stochastic in nature. Therefore lethality is measured by the probability a target will be killed by the weapon, P_K. It is obvious that the target survival and target kill are mutually exclusive events. Accordingly, this relation is given by

$$\text{[Weapon Lethality]} = 1\text{-[Target Survivability]}$$
$$P_K = 1 - P_S \tag{3.1}$$

Target survivability is affected by target susceptibility, which refers to the inability of a target to avoid being hit, and vulnerability, which refers to the weakness of the target against the given hit. In other words, to kill the target, it must be hit by one or more damage mechanisms associated with the weapon propagator warhead, and the hit(s) by the damage mechanisms must result in a target kill. Hence, weapon lethality is measured by the joint probability that the target is hit, P_H, and killed given the hit, $P_{K/H}$.

$$\text{[Weapon Lethality]} = \text{[Target Susceptibility]} \times \text{[Target Vulnerability]}$$
$$P_K = P_H P_{K/H} \tag{3.2}$$

2. SAM Operating Process ~ One-on-One Encounter

According to Ball [Ref. 13], a one-on-one encounter can be divided into five sequential phases and events in the susceptibility portion: (1) the AD system must be actively searching for targets entering into its searching space (Target exposure), (2) the AD system must detect targets (Encounter), (3) the AD system must engage the detected target by firing/launching a propagator, such as a ballistic projectile or guided missile (Engagement), (4) the propagator must 'fly out' and intercept the target (Intercept), and (5) the damage mechanisms carried by the warhead on the propagator must hit the target

(Endgame). In the very last phase, the target vulnerability has to be considered, that is (6) the target must be killed by warhead detonation. Figure 2 illustrates the phases and events of detection, launch, fly out, and endgame, with appropriate ranges and times, known as time lines.

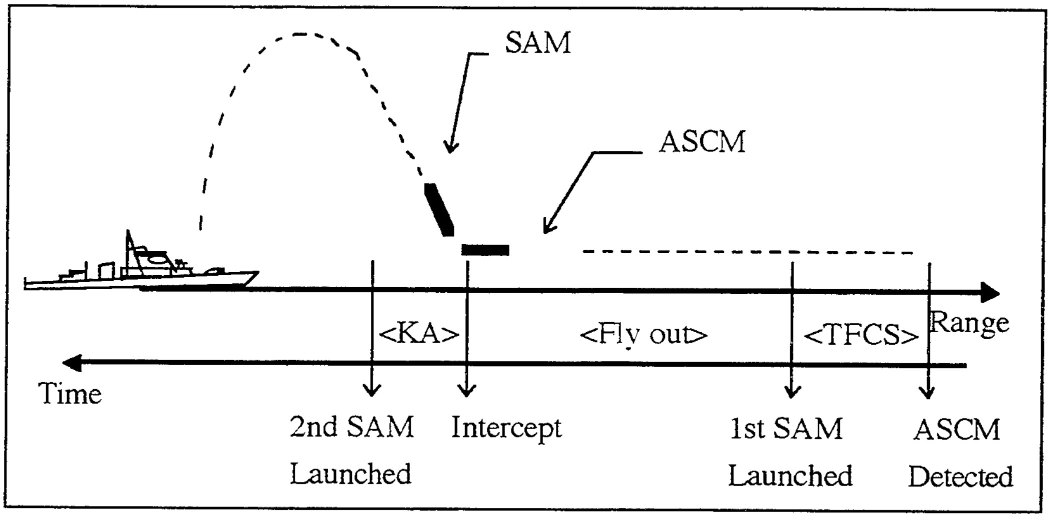

Fig. 2. Time Line of Encounter
(TFCS: Target Fire Control Solution, KA: Kill Assessment)

The outcome of each phase or event is clearly not deterministic. Therefore each phase can be represented by the following probabilities:

- P_A : The probability that the weapon system is active and ready to encounter
- $P_{D/A}$: The conditional probability that the weapon system will detect a target given that the weapon system is active.
- $P_{L/D}$: The conditional probability that the target has been tracked, a fire control solution is obtained, and a propagator is launched at the target, given that it has been detected by the active weapon system.
- $P_{I/L}$: The conditional probability that the propagator 'flys' out, possibly guided through the midcourse and terminal phases, and successfully intercepts the target.
- $P_{H/I}$: The conditional probability that the warhead hits or effectively detonates, which is dependent on warhead type, against the target, given successful conditions above.

$P_{K/H}$: The conditional probability given that the target is killed by the hit or detonation.

Thus the probability that the target is killed is in as follows,

$$P_K = P_H P_{H/K} = (P_A P_{D/A} P_{L/D} P_{I/L} P_{H/I}) P_{K/H} \tag{3.3}$$

Estimation of the lethality of the weapon is one of the hardest questions to answer. It depends not only on the weapon parameters but also on the target performance represented by susceptibility and vulnerability. In addition, environmental factors and the scenario also affect it. Usually weapon lethality is provided by the manufacturer based on some specific simulation or by historical data. An example is the demonstrated lethality of Harpoon which has been about 93% in 374 launches (100% since 1982) [Ref. 16: p. 187].

3. Lethality Assessment

Let us devote a little more space to discussing what the reasonable estimations or assumptions for each of the above probabilities are in order to use them in a spread sheet model.

First, P_A stands for mainly weapon system reliability and readiness in the given environment. It could be assumed $P_A = 1.0$ for simplicity. However if a system consists of several platforms and the activity of each of platforms affects the total system outcome, it could be better to consider the P_A of each platform.

Secondly, $P_{D/A}$ could be a variable of the range from the AD sensors. It means we can expect that an initial detection of a particular target occurs at some specific range with a particular probability. To put it another way, under the given conditions, we may estimate the detection range, R_D, at which point $P_{D/A}$ changes from 0.0 to 1.0. For example, suppose we cannot detect the target until it hits the AD system. The detection range is zero. However, in reality we cannot estimate the detection range exactly because of uncertain information of conditions, especially environmental factors such as sea state, ducting and multipath effects, etc. Therefore, we suppose the AD system can always detect the target at the radar horizon based on the radar height and a target altitude. Then, some probability distribution which represents the likelihood of the target detection occurring within small range intervals, will be applied to the entire range.

Thirdly, $P_{L/D}$ can be represented by the time delay or reaction time, since the most interesting aspect in this phase is how fast we can fire/launch after initial detection. Thus,

we assume $P_{L/D}$ becomes 1.0 after some time delay from detection and change it by a given condition in the same way as the relationship between $P_{D/A}$ and R_D. It also seems reasonable to say that the reaction time can be divided into three parts. These are the initial reaction time, dt_I, the target fire control solution time delay, dts, and the launcher reaction time, dt_L. Dt_I "consists of getting personnel in 'combat ready' positions and transferring the equipment from a standby alert status to a fully operational status." [Ref. 21: p. 95] It represents the combat condition status and the training level. Dts stands for the time for firing based on the capability of combat system and the commander's final decision. It must be necessary to figure out the target location, flight path, and status which is based on the interrogation of IFF before firing. Dt_L represents launcher characteristics.

At last, we assume that the remaining probability components $P_{I/L}$, $P_{H/I}$, and $P_{K/H}$ can be lumped together and represented by one probability, P_{KSS}, or the probability the target is killed given a single shot. The main reason is that in order to estimate these values, we need to run simulations at very high resolution by using specific weapon and target characteristics values. These data are usually classified. Thus, the study of these detailed simulations lies outside the scope of this paper. Consequently, P_{KSS} is assumed to be given and is used as an input variable.

4. Layered Defense

> In essence, air defense at sea is 'layered' from the point of origin of the threat to its intended point of impact. [Ref. 32: p. 50]

In general layered defense or defense-in-depth consists of basically point/organic defense and area defense. In case of a U.S. carrier battle group, the area defense divided into two layers: the fighter engagement zone (FEZ), where the combat air patrol aircraft (CAP) and deck launched interceptor (DLI) fight the approaching enemy fighters and bombers, and the missile engagement zone (MEZ) using long and medium range SAMs. However in this thesis we assume no support of CAP and focus on the very low altitude where the radar horizon lies as one of the most restrictive conditions. Therefore, as shown in Figure 3, it is better to define the outer-most layer as the Over the Horizon (OTH) SAM engagement zone and the next layer as the long range SAM engagement zone. This zone is restricted by the ship-board illuminator horizon for semi-active homing missiles. We assume the short range point defense weapons guard the last defended area. This consists of three layers based on maximum effective range. They are the short range SAM layer, the Gun layer, and the combined CIWS and soft kill weapon layer. We assume that each five

weapon layers has its own PKSS against an ASCM, and the PKSS is constant within the layer.

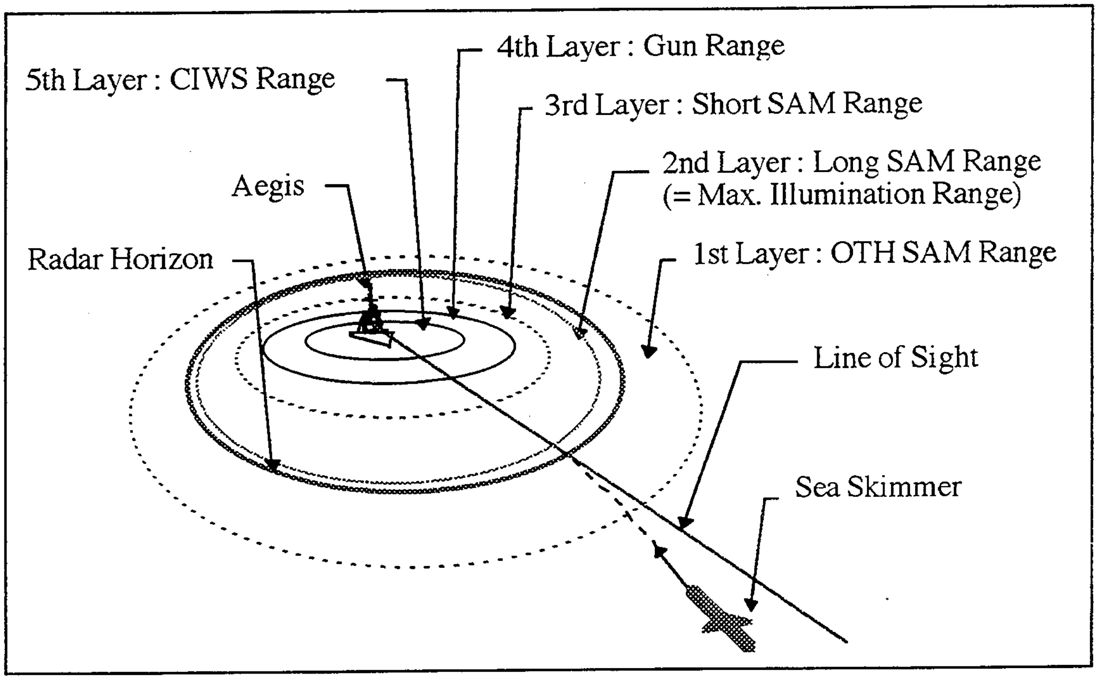

Fig. 3. Aegis AAW Layer

5. Assumption of ASCM Flight Profile

The flight profile model of ASCM is simplified to a straight path holding constant altitude as shown in Figure 4. The ASCM is characterized by its average incoming speed (an input value) in our model. The cruising altitude (an input value) affects the radar horizon. The other aspects of the ASCM such as maneuverability, are included in the PKSS for Aegis weapons in each layer which is an input value.

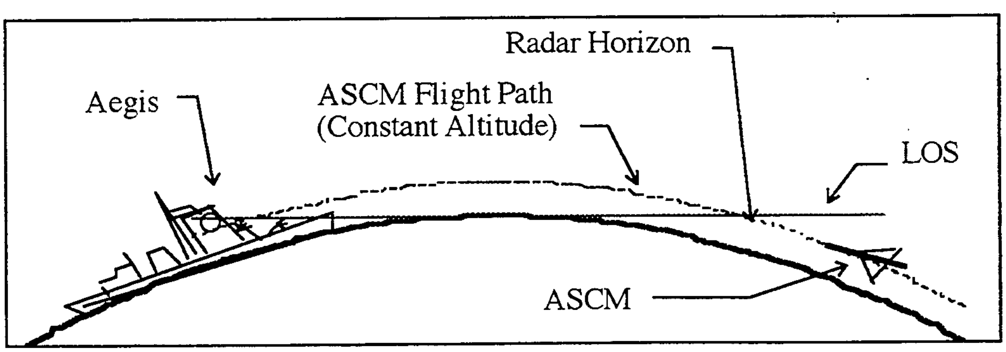

Fig. 4. ASCM Flight Profile and Radar Horizon

The target of the ASCM can be either the Aegis ship or a FSU which is stationed at some point away from Aegis. If an ASCM is approaching the FSU, the threat axis is defined as the line passing through the ASCM and FSU positions. The worst case scenario in terms of the available Aegis reaction time is when the Aegis ship is also on that axis but behind the FSU. This situation also allows us to ignore the bearing of a target. Thus, the model becomes two dimensional (2-D), range and height. If it is reasonable to assume the Aegis propagators (guns and missiles) fly out with constant horizontal speed, the simplest one dimensional model (1-D) can be used.

6. Computation of Aegis Lethality

To estimate the Aegis lethality against an ASCM, we compute an intercept point, R_{INT}, of an Aegis propagator and the ASCM. In the simplest 1-D case, the time from the initial detection to the interception, T_{INT}, is given by:

$$T_{INT} = \frac{\left(R_{DET} - (dt_i + dt_S + dt_L) \cdot V_{ASCM}\right)}{\left(V_{SAM} + V_{ASCM}\right)} \tag{3.4}$$

where R_{DET} is the initial detection range, $(dt_I + dt_S + dt_L)$ is the total time delay mentioned in the previous section, and V_{SAM} and V_{ASCM} are the average horizontal speed of the Aegis propagator and the ASCM respectively. Then, by using T_{INT}, R_{INT} is estimated by:

$$R_{INT} = V_{SAM} \cdot T_{INT} \tag{3.5}$$

If R_{INT} is greater than R_{MAX}, the maximum fly out of the Aegis SAM, the first shot is delayed until the intercept would occur at R_{MAX}. After this first engagement, the Aegis needs some time to determine the results of the shot, which is referred to as the target kill assessment (TKA). If the first shot is determined to be a failure, a second shot is launched immediately after the target fire control solution (TFCS) is obtained. It is noted that the time delay due to the TKA to TFCS is much less than the delay from the initial detection to the TFCS of the first shot. The next intercept time after the first intercept is given by:

$$T_{INT} = \frac{\left(R_{INT} - (dt_{KA} + dt_L) \cdot V_{ASCM}\right)}{\left(V_{SAM} + V_{ASCM}\right)} \tag{3.6}$$

where dt_{KA} is the time delay of TKA and TFCS. The subsequent intercept ranges are calculated using Equation (3.5) and (3.6).

When examining the intercept range, the launching system should be considered. The Mk-41 Vertical Launch System (VLS) is installed on the Aegis instead of a trainable launching system, such as Mk-26 GMLS. The features of VLS are to eliminate the launcher sweep motion and to send a SAM toward a low air density altitude as fast as possible. Elimination of former results in increasing the launching speed, especially against simultaneous multi-direction attacks, and also increasing the system reliability since it is a multi-parallel system. The latter reduces drag and increases the SAM speed. Consequently, it allows fast and long range interception even though the flight path is longer. However, in case of shooting at a short range target, this longer flight path would cause a longer intercept time. The manufacturer of Rolling Airframe Missile (RAM) argued that:

> the trainable (as against vertical) launcher reduces the crucial 'fly out' time to the incoming missile. [Ref. 28: p. 61]

To include up and over trajectory, the 1-D model should be modified into 2-D. However, to consider the detailed guidance and propulsion of Aegis/SM-2 missile system is not the point of this thesis. The available data is also scarce. Therefore, the modification to the missile flight path to account for a vertical launch is limited to a very simple Proportional Navigation (PN) guidance program to simulate a SAM 2-D flight profile. Further modifications are left for future study. Appendix B describes this PN program.

After the intercept points are determined, applying the given P_{KSS} at each point results in the probability of target kill at that point. If the individual encounters are assumed to be independent events, the target survivability, or the probability of a "leaker" after N shots, Ps, is given by:

$$P_S = \prod_{i=1}^{N} (1 - P_{KSS(i)})^i \tag{3.7}$$

On referring to Equation (3.1), the lethality of Aegis is:

$$P_K = 1 - \prod_{i=1}^{N} (1 - P_{KSS(i)})^i \tag{3.8}$$

In our Aegis AAW model, there are five layers, each of which has a fixed P_{KSS}. If the total number of possible encounters within the ith layer is N(i), the following equation is obtained:

$$P_K = 1 - \prod_{i=1}^{5}\left(1 - P_{KSS(i)}\right)^{N(i)} \qquad (3.9)$$

By using Equation (3.9), the lethality of Aegis due to several points is computed.

7. Measures of Effectiveness (MOE)

> Select measures of effectiveness that relate directly to a system's performance characteristics and to mission acomplishment. Dicision makers need to know the contribution of the system to the outcome of battle, not just how far it can shoot or how fast it can fly. [Ref. 33: 8-8]

It is useful to examine the method by which the JMSDF Aegis destroyer operational effectiveness should be measured. Even though the different missions require different outcomes, it seems reasonable to characterize mission requirements by establishing "a denial area at an acceptable risk". A denial area at an acceptable risk refers to that area of coverage by Aegis within which it has an desirable level of lethality P_K against an air target, such as an ASCM. If no FSU loss is required during a mission, the acceptable risk is 0.0, which is the same as a 1.0 lethality against the threats. What must be clear is that the lethality provided by Aegis at some point is not always equal to the total lethality at that point. The reason is that it may be enough for Aegis to provide 0.8 lethality to a FSU in order to achieve a total 0.95 scenario lethality. This is because the FSU has some self defense weapons which provided some lethality against threats such as 0.75.

From this point of view, missions can be categorized into two types: tanker escort and blocade. The tanker or high value unit (HVU) escort which is a traditional mission of the JMSDF. In this operation, there is no reason for stationing the tankers away from the escort ship. The only concern is to kill the ASCMs before they hit the tankers. It is not so important to be able to kill ASCMs a long distance away. It implies the denial area is small, probably a circle with a few thousand yards diameter and fixed. However, what is expected is no risk (zero leakers) within this given area. Therefore the measure of effectiveness (MOE) is how much lethality can be expected at the given range at the edge of the denial area. In other words, we want higher lethality in a fixed volume of space.

The other type of mission includes blockades for protecting a maneuvering friendly force, or securing a free shipping area. Here, it is desired to expand the denial area as much as possible for these operations. As the denial area is expanded, Aegis can not provide high lethality to the entire area. The possibility of a "leaker" which penetrates the Aegis area

defense and proceeds to its target could increase. Therefore, the FSU has a certain risk of ASCM penetration. The acceptable level of risk is dependent on the mission. If some deterrent effects or presence is desired, the capability of denying as large a space as possible could be very important even though the actual lethality is not so high. Thus the MOE for this type of mission is how much area can be secured within a required lethality. It is also reasonable to use this MOE to evaluate the operational flexibility or multi-mission capability.

To sum up, a given mission is characterized by the two associated concepts of "denial area" and "acceptable risk". It is reasonable to use the lethality provided by Aegis as a parameter of "acceptable risk" since it implies the quantity of possible "leakers". It is also right to adopt the range where required Aegis lethality level is achieved as a parameter of "denial area". As a result, we examine the effectiveness in two ways.

1) What level of Aegis lethality can be expected at a given required range?
2) What range can be secured with required Aegis lethality levcl?

The former is suitable for tanker escort type missions. The latter represents the appropriateness of area expansion type missions. It also provides the basic information to estimate how many ships we need to cover a required area. In a sense, it represents the operational flexibility since the larger area implies the grater potential of a variety of missions.

One more important element that should be considered regarding the expected capability of Aegis is the role of the intelligence center as a battle field manager. Because of its complexity, this is difficult to quantify. Consequently, it will be subjectively examined later.

8. Expected Value Spread Sheet

To measure the operational effectiveness of Aegis AD, computed lethalities are compared to the required lethality, P_{KR} (an input value), which represents the "acceptable risk" derived from a mission. Then, the point at which P_{KR} is achieved is picked out as the edge of the "denial area". When the required range, R_R (an input value) , which represents the "denial area" of a mission is given, the lethality at this point is the value at the nearest outer intercept point.

Additional assumptions are as follows:

1) If the ASCM is detected once, it will never be lost.
2) The weapon system is always active. In other words, the system reliability is 1.0
3) A series of shots from the gun is represented by the first shot with the given PKSS(4) which is the cumulative value of the series. For example, if the PKSS is 0.02 and 25 shots are expected within the effective range, PKSS(4) is 0.3965.
4) In the CIWS layer, PKSS(5) represents combined effectiveness of "hard kill" and "soft kill" weapons. The intercept occurs only once at a fixed point.
5) The minimum effective range, Rmin, of a weapon is same as the maximum effective range, Rmax, of the next inner layer weapon.
6) The firing doctrine is "shoot-look-shoot". If "shoot-shoot-look" is used, the two shots are lumped into one shot. It means the input value of PKSS is changed. For example, if the PKSS is 0.7 in "shoot-look-shoot", then the PKSS is changed to 0.91 in order to estimate the "shoot-shoot-look" doctrine case.
7) As long as the estimated intercept range is longer than the Rmin, the weapon continues to fire. If it is less than Rmin, the next inner weapon will be fired.

9. Simulation with Crystal Ball

In reality, input variables such as PKSS, time delay, initial detection range is not exactly the expected values. They include uncertainty in nature which could be represented by a certain probability density function (pdf). To assess the effect of stochastic events, Monte Carlo simulation can be used. If we have the expected values spread sheet, these variance effects are easily included by using the add in program named Crystal Ball. Crystal Ball is used to account for the probabilistic pdf nature of the input variables and to assess the probability of the output results.

> * You can describe a range of possible values for each uncertain cell in your spreadsheet. Everything you know about each assumption and how it affects your result is expressed all at once.
> * Using a process called Monte Carlo Simulation, Crystal Ball displays your results in a forecast chart that shows the entire range of possible outcomes and the likelihood of achieving each of them. In effect, Crystal Ball moves you beyond "what -if" scenarios by providing an accurate statistical picture of the range of possibilities associated with your assumptions. [Ref. 34: p. 15]

Using this program, a certain assumed pdf is applied on the initial detection range cell in the expected value spread sheet and the first intercept point is observed as a forecast cell value in order to understand the effect of variability of initial detection range.

10. Monte Carlo Simulation Spread Sheet

A Monte Carlo simulation spread sheet was developed in order to examine the consumption of Aegis weapons during a mission and the effectiveness of using an FSU's point defense system, which is combined with Aegis area defense weapons. The weapon consumption is critical problem, especially in a mission that includes TBMD:

> Arguably, the most critical item facing the deployment of a sea-based theater ballistic missile defense is the issue of developing a warhead that can defeat all possible ballistic missile threats. ... That warhead may be unique in that it could only be used for ballistic missile defense. If that is the case, there would have to be a magazine mix on the Aegis. That would mean that some cells and launchers would have to be dedicated to ballistic missile defense. That would take away from the number of missiles available for other AAW and strike missions. ... This leaves open the possibility for the ship or the area it is trying to defend to be saturated or overwhelmed by the adversary. [Ref. 35: p. 80]

To install a point defense system on an FSU could be another option to increase the success of a mission. It would be worthwhile to simulate this situation. The basic computation is same as the expected value 1-D model. The number of each weapon, the FSU position from Aegis, a P_{KSS} of FSU point defense system, and the expected number of ASCM attacks are added as input variables. Each attack occurs sequentially. Which target, the Aegis or the FSU, an ASCM will attack is determined by an input variable of the attack ratio of FSU. If every ASCM attacks to the FSU, the attack ratio is 1.0. If the target is Aegis, the attack ratio is 0.0. If equally attacked, the ratio is 0.5. However, if Aegis is killed, all remaining ASCMs will attack the FSU. When the FSU is sunk, this trial is terminated and the mission is a failure. When the FSU survives against all attacks, the mission is a success, even if the Aegis is damaged. The condition of a ship kill is defined by the user as a number of necessary hits to kill the target ship.

Both the expected value spread sheet and the Monte Carlo simulation are made by using the Microsoft Excel version 5.0 for Macintosh. Example spread sheets and the programs are shown in Appendix C and D respectively.

B. EXAMPLE CASE STUDY

This thesis focuses on the operational effectiveness for the area expansion type mission in a littoral area using long range SAMs. A study of improving the point defense system for own-ship survivability, such as the effectiveness of weapons combination, or a short range SAM improving, are left for a future study. Improvements of the SAM area

defense system components due to a reduced time delay, an increased SAM speed, an increased SAM maximum range, and an increased detection range will be examined.

1. Base Aegis System and Threat

a. Base Aegis System

The current JMSDF Aegis is assumed to be characterized as follows

Radar height: 55 feet
Illuminator height: 60 feet
The maximum range of SAM: 40 NM (it is also limited by the illuminator horizon)
No short range SAM nor OTH SAM
Detection range: Radar horizon
The time delays are listed in Table 3.
Characteristics of weapons are listed in Table 4.

Time Delay	dt_I	dt_S	dt_{KA}
(sec)	5.0	3.0	1.0

Table 3. Base Aegis Time Delay

Weapon	OTH SAM	SAM	Short SAM	Gun	CIWS
Speed(Mach)	-	2.0	-	2.0	-
P_K	-	0.7	-	0.4	0.5
max. R(NM)	-	40/IH	-	5.0	1.0
dt_L(sec)	-	2.0	-	5.0	2.0

(IH: Illuminator Horizon)

Table 4. Base Aegis Weapon Characteristics

b. Threat

In this study, we focus on a "sea-skimmer". The incoming altitude is taken as 40 feet above water. As seen in Chapter II, supersonic sea-skimmers, such as ANS with Mach 2.0, Moskit with Mach 3.5, are the most dangerous threats in the foreseeable future.

Therefore, the impact of supersonic ASCMs is examined. A subsonic ASCM (Mach 0.9 like Exocet) case is the reference standard of current system lethality level.

2. Improvement Requests

It is obvious that there are two big constraints in the base Aegis system. One is the detection range, which is limited by the radar horizon, 16.9 NM. It means a denial area cannot be expanded beyond 16.9 NM even if an effective weapon range is more than that. The other constraint is the illuminator horizon of SAM launched ship since a semi-active homing missile require a terminal guidance by an illuminator. Thus, the weapon envelop of the base system is limited to 17.3 NM in this case. If a mission requires more denial area than 17.3 NM radius, the weapon envelope has to be expanded by using other missile and guidance systems. Without this, the other improvements are useless. However, if a mission is achievable within the base system's possible denial area, the requirement would be to keep this denial area against future threats. Thus, we will examine how denial area shrinks by supersonic sea-skimmers and find the effective solutions to keep a reference denial area.

Suppose a mission requires more than 10 NM at a 0.3 acceptable risk as the reference standard. The 0.3 acceptable risk, which means the 0.7 Aegis lethality, implies that an edge of the denial area is same as the first intercept point of the SAM. It means this range is the maximum possible denial area of a system, since it is impossible to expand a denial area beyond the first intercept point. Therefore, using this acceptable risk should be a good way to focus on the essential elements of area expansion. However, to examine the possibility of more than two salvos is also important since "a missile carrying decoys and jammers could, in theory, neutralize the first salvo and also confuse damage assessment." [Ref. 20: p. 43] Therefore, the range at 0.9 P_{KSS}, where the ASCM has to be intercept twice, is also examined.

3. What If Analysis of Expected Value Model

First of all, to judge the base Aegis system, the change of ranges at P_K =0.7 and at P_K=0.9 against the increased speed of ASCM will be observed. Then, using this results as a reference standard, the following five improvements alternatives will be compared.

1) What if the time delay, from initial detection to SAM launching, can be reduced to 5 seconds or 3 seconds from 10 seconds of base case?

It implies that higher target tracking rate, increasing fire control computation time and launcher reaction time, trained person, higher weapon condition, etc..

2) What if the SAM average horizontal speed can be increased to Mach 3.0 or 4.0 from Mach 2.0 of base case?
It would includes actual SAM speed up and optimum flight path.

3) What if combined above two improvements can be done?

4) What if the initial detection range can be expanded?
It means mainly using off-board sensors. The assumption here is that Aegis can launch a SAM by using the target data from external sources. In other words, the direct target detection by SPY-1 is not required.

5) What if the variability of detection range can be reduced?
It implies the multi-sensors fusion. Using assumed distribution in the "Crystal Ball" and try to grasp a general idea.

4. What If Analysis of Monte Carlo Simulation

Suppose Aegis is loaded with 60 SAMs, the stationing point of the FSU is within the denial area at $P_K= 0.9$, and 10 ASCM attacks are expected during mission. The relation of the hostile attack intention, the FSU self-defense capability, and SAM consumption will be considered. As example study, the attack ratio is taken as 0.5 and 1.0. The FSU self-defense capability is examined the cases of $P_K =0.0$ and 0.5. A single hit on a FSU by an ASCM is taken as a ship kill.

IV. RESULTS

A. RESULTS

1. Improvement Alternatives ~ Expected Value Spread Sheet

Figure 5 shows the change of the edge of the two denial areas, (P_K=0.7 and P_K=0.9) due to an ASCM's speed. In other words, the line for P_K=0.7 represents the first intercept point against an ASCM, and P_K=0.91 is the second intercept point. Suppose a mission requires more than a 10 NM radius of denial area and the minimum effective range of SAM is 4 NM.

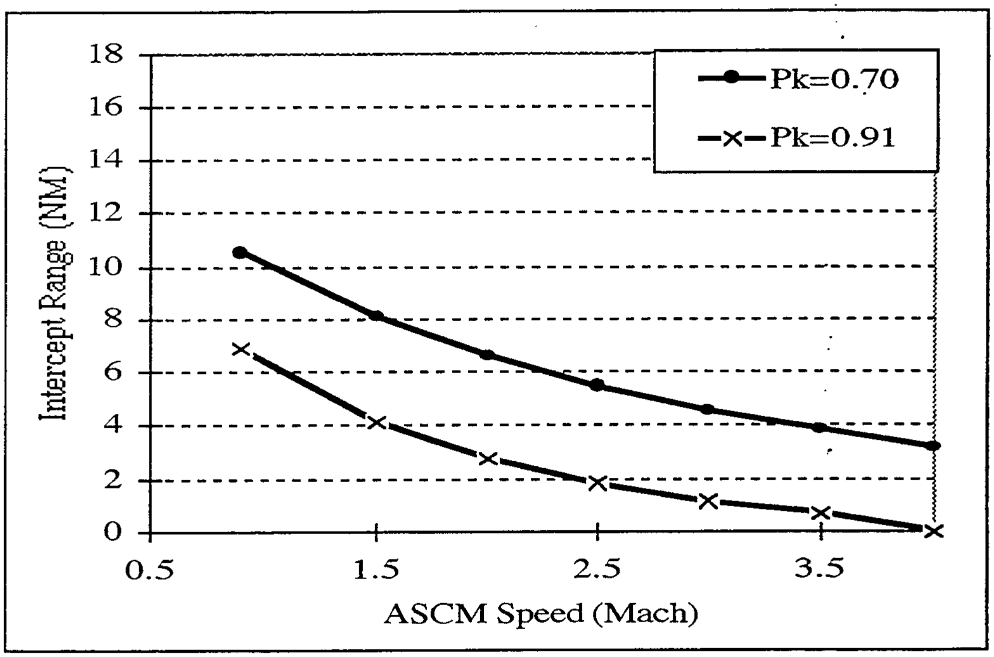

Fig. 5. Intercept Range of Base Aegis

The base Aegis system can handle a Mach 0.9 ASCM. However, when the ASCM is approaching supersonically, it cannot secure the required mission area, and more than 1.5 Mach ASCM would permit only one intercept chance prior to the minimum SAM effective range. Clearly, the base Aegis has to be improved to deal with a supersonic sea-skimmer.

Figures 6 and 7 indicate the impact of reducing the reaction time delay. They reveal that this course of action gives very little benefit. From another point of view, marginal effectiveness is small since the Aegis combat system is already at high level, and also the human reaction time and IFF may be the dominant factors of time delay. Furthermore, a fully automatic weapon condition is impossible in the littoral area in practice, because a weapon release is usually restricted by rules of engagement. Although a noticeable point in this improvement is that the sensitivity is increasing as ASCM's speed is faster, it does not contribute to the area of expansion so much.

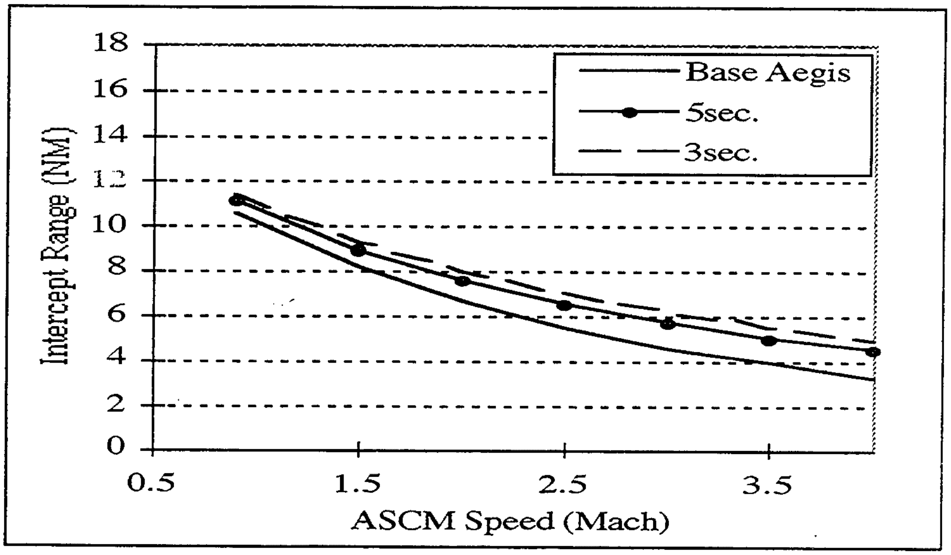

Fig. 6. Reduction of Time Delay (PK=0.7)

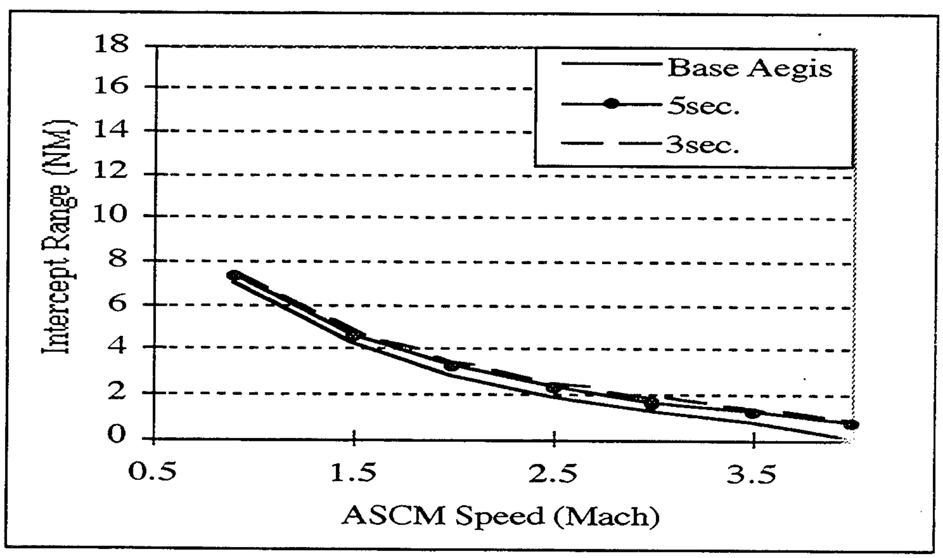

Fig. 7. Reduction of Time Delay (PK=0.91)

Figures 8 and 9 show the impact of increasing SAM speed. It is better than the reduction of time delay improvement, especially in the opportunity of the second shot. However, it doesn't seem to be enough improvement, and also the improvement effect is gradually diminishing as ASCM is faster. Adding to that, the increase of SAM speed would affect the PKSS. If the increasing speed causes a reduction of PKSS, the obvious improvement is to just extend the possible maximum intercept range a couple of miles, since no matter what the level of lethality we can get, it is better than nothing.

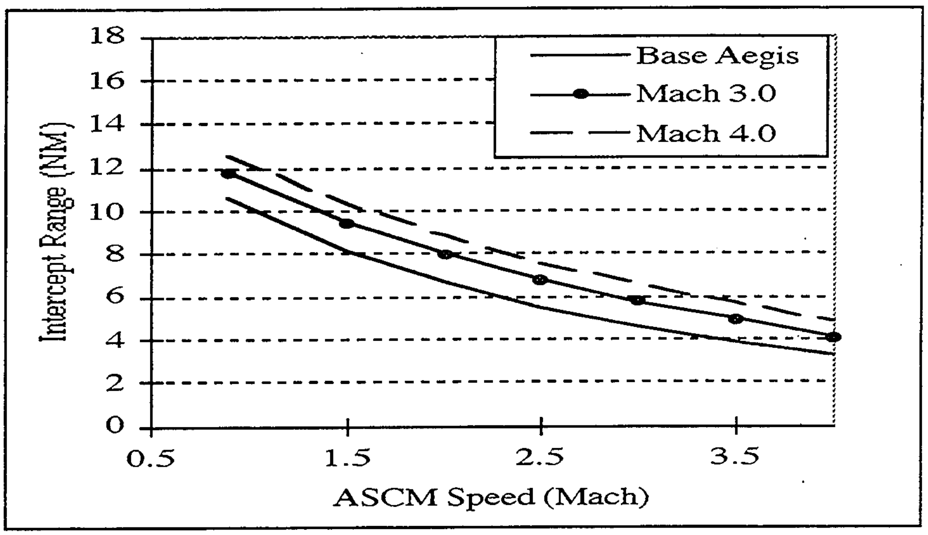

Fig. 8. Increase of SAM Speed (PK=0.70)

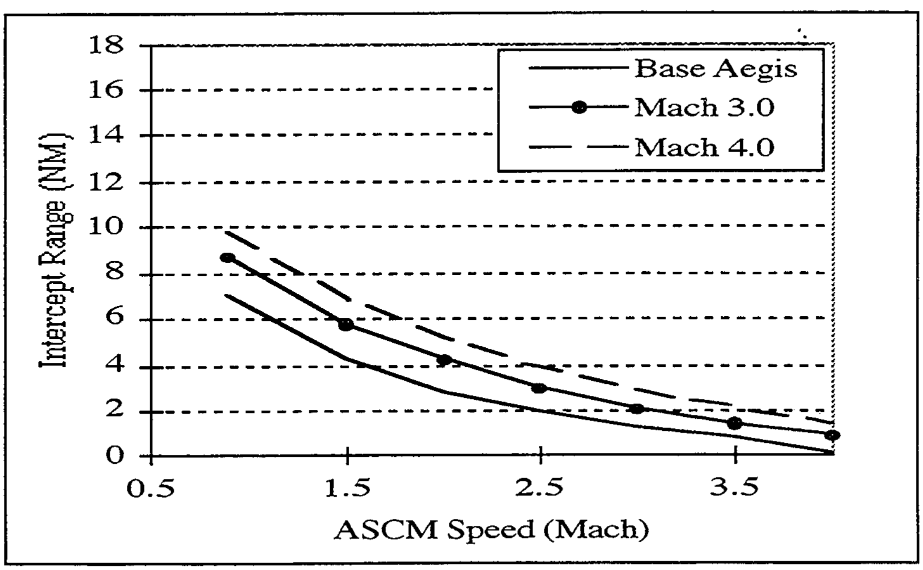

Fig. 9. Increase of SAM Speed (PK=0.91)

Figures 10 and 11 show the impact of combining the two improvements (time delay and SAM speed): using Mach 3.0 SAM with 5 seconds reaction time and Mach 4.0 SAM with 3 seconds reaction time. This improvement could be effective against at most a Mach 2.0 ASCM. However, even though two components, combat system and SAM, can be successfully improved, we can never neutralize a "Moskit" missile traveling at Mach 3.5.

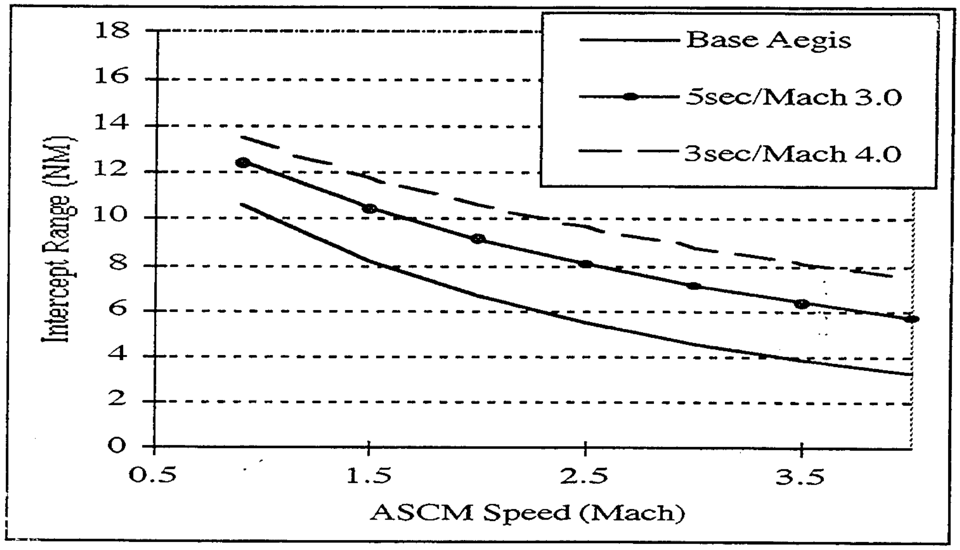

Fig. 10. Reduction of Time Delay and Increase of SAM Speed (PK=0.70)

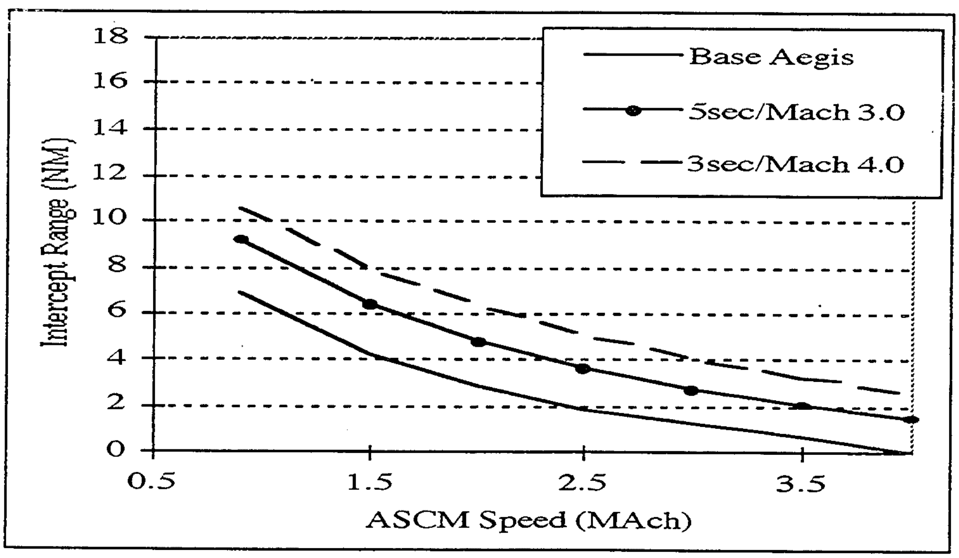

Fig. 11. Reduction of Time Delay and Increase of SAM Speed (PK=0.91)

Compared to these improvements, the effort of expanding the sensor envelope to 40 NM or 60 NM leads to very impressive results. As seen in Figure 12 for a 40 NM detection range, the first intercept range is dramatically extended. We can achieve to secure 10 NM radius of mission area against a Mach 3.5 ASCM by extending the detection range up to 40 NM. In case of getting a 60 NM detection range, Aegis can use the maximum range of the SAM (17.3 NM), which is limited by the illuminator horizon, even though an ASCM's speed is Mach 3.5. Furthermore, Figure 13 shows that a 60 NM radius of detection envelope could guarantee the intercept of the second shot beyond the minimum effective SAM range. The only concern could be the reduction of PKSS by using off-board sensors for the SAM guidance. However, the second shot could be guided from the launched ship by using own SPY-1. It means the expected PKSS for the second shot is same as the base Aegis system. The intercept point of second shot is almost the same as the first intercept point of the base Aegis. Therefore, the degradation would be minimized.

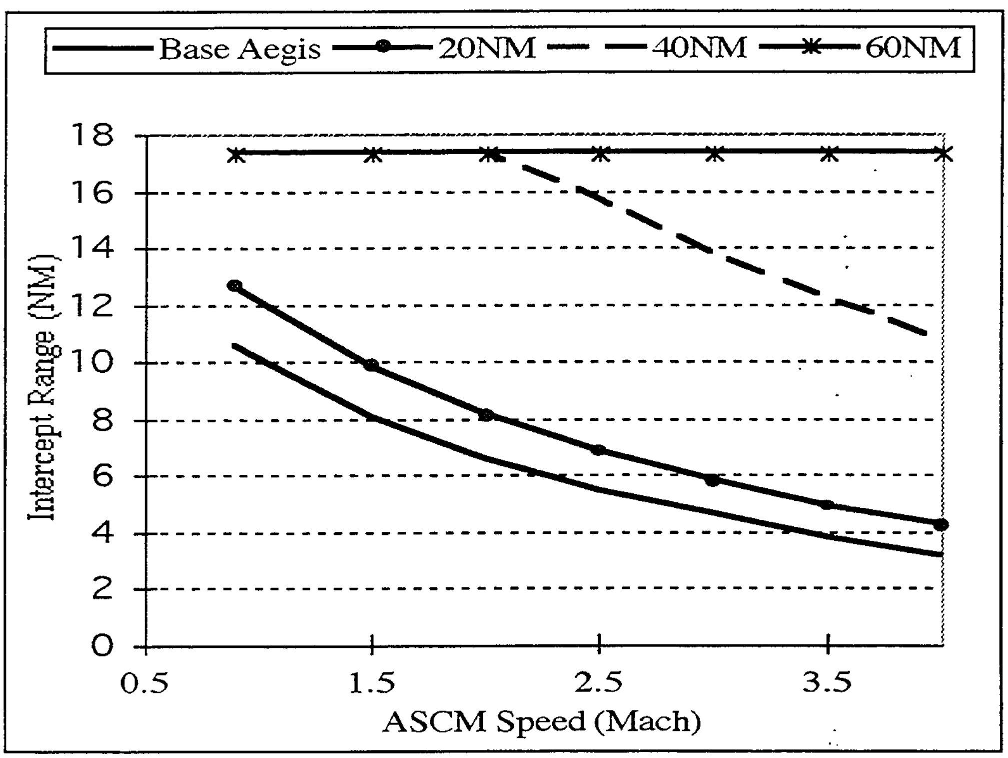

Fig. 12. Extension of Detection Range (PK= 0.7)

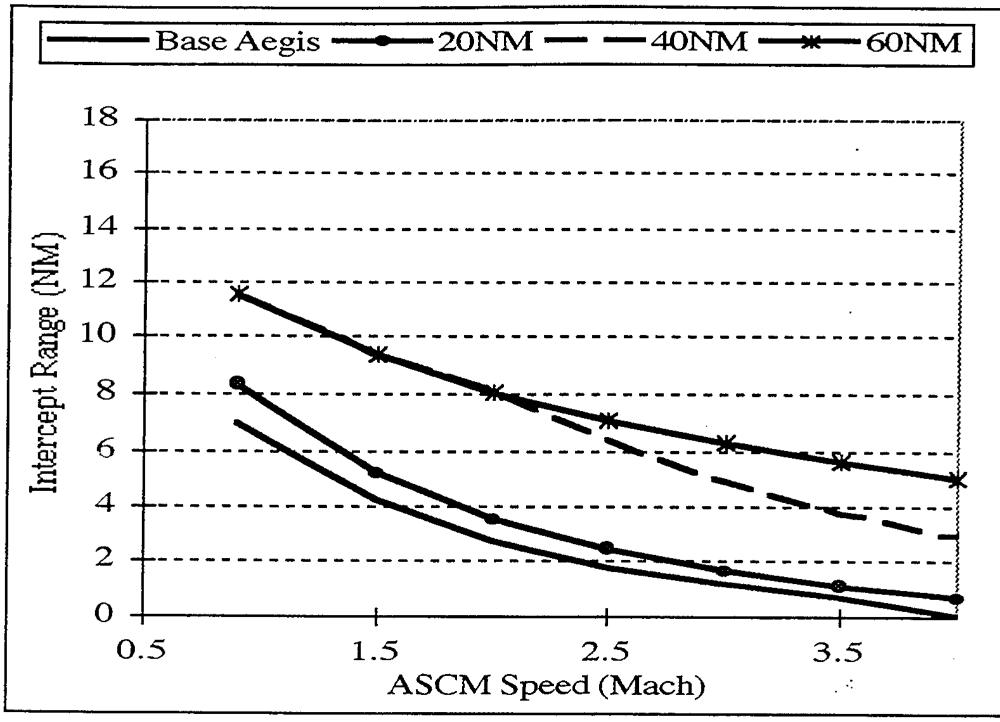

Fig. 13. Extension of Detection Range (PK=0.7)

To understand the range and time line of sequential events in these scenarios, let's look at it another way. Figure 14 shows the remaining time of each improvement alternative until a Mach 0.9 ASCM hits Aegis. From right to left, each component of the bar represents a sequential event: Initial detection to getting a target fire control solution (TFCS), TFCS to launching the first SAM, the SAM fly-out to intercepting the target, kill assessment to the second SAM launching, the second SAM fly-out and intercepting the target. Thus, the left most part of the bar tells the remaining time when the second intercept can occur. Figure 17 shows the range from Aegis instead of the remaining time in Figure 14. Figures 15 and 18 are the Mach 2.0 ASCM case, and Figures 16 and 19 are the Mach 3.5 ASCM case. To extend the detection range stretches the bar size instead of just changing the ratio of each component. The important point is the TFCS to the first SAM launch. Extension of this allows an intercept of the target at the maximum range of the SAM. It provides the room for compensating the Aegis for the variability of the initial detection range and time delay. In addition to that, it allows the future extension of SAM maximum range.

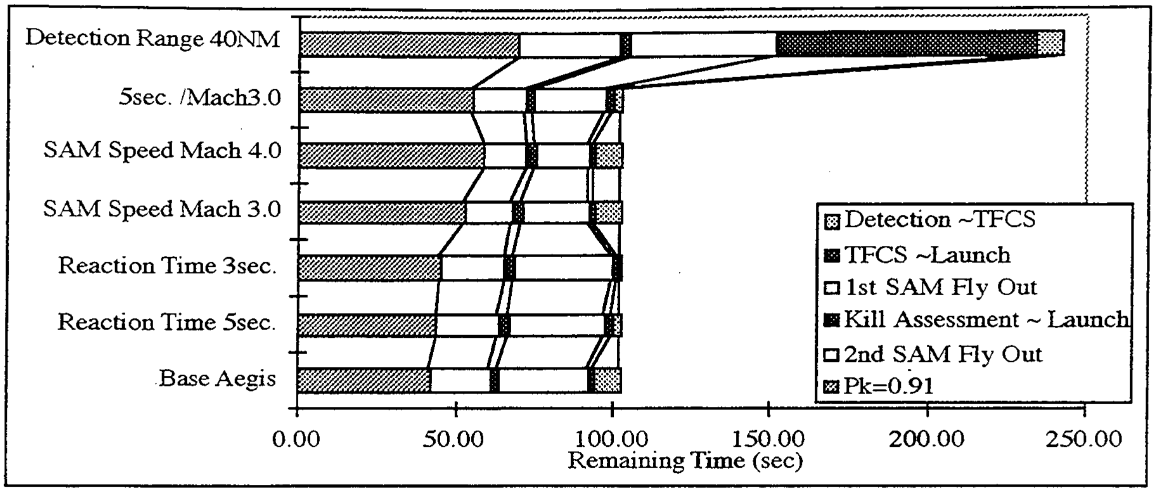

Fig. 14. Improvement Alternatives and Sequential Events (Time): Mach 0.9 ASCM

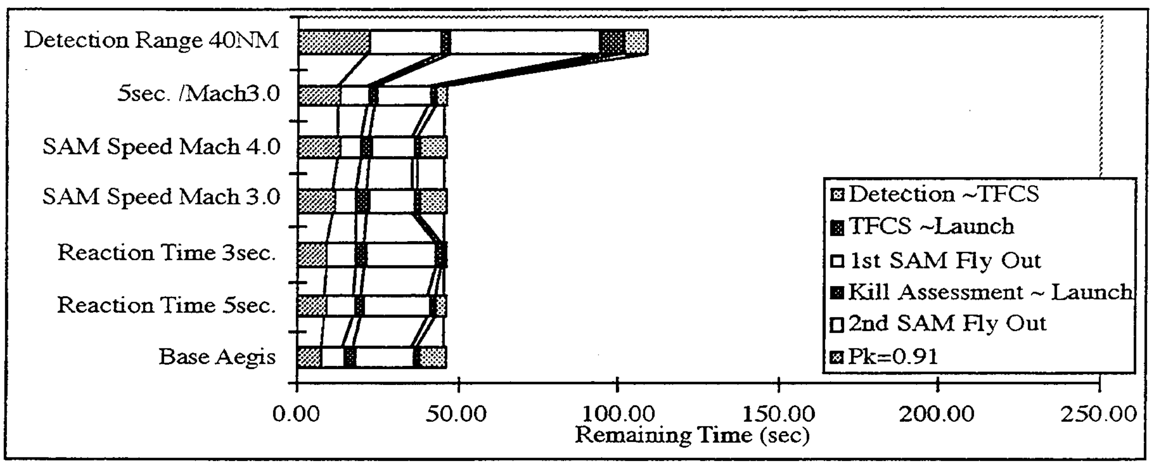

Fig. 15. Improvement Alternatives and Sequential Events (Time): Mach 2.0 ASCM

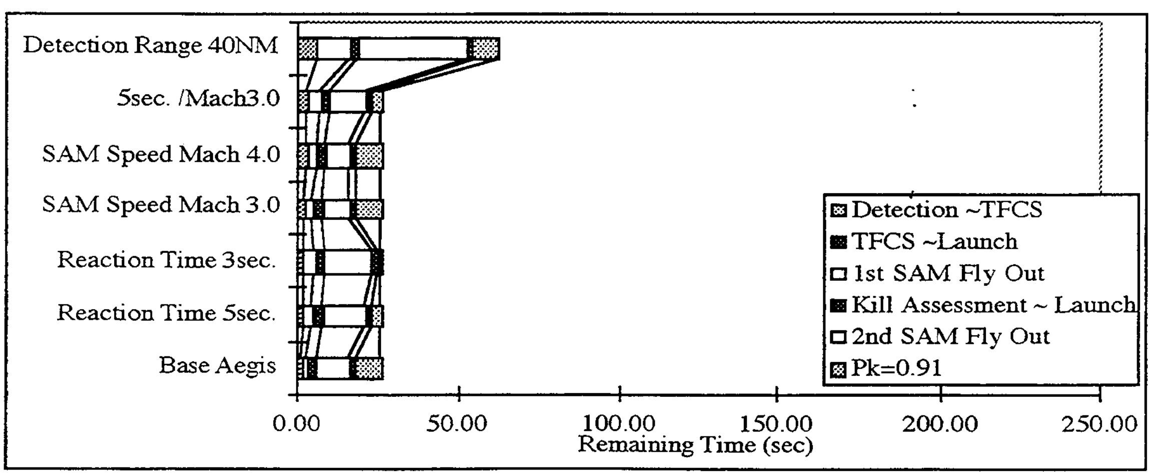

Fig. 16. Improvement Alternatives and Sequential Events (Time): Mach 3.5 ASCM

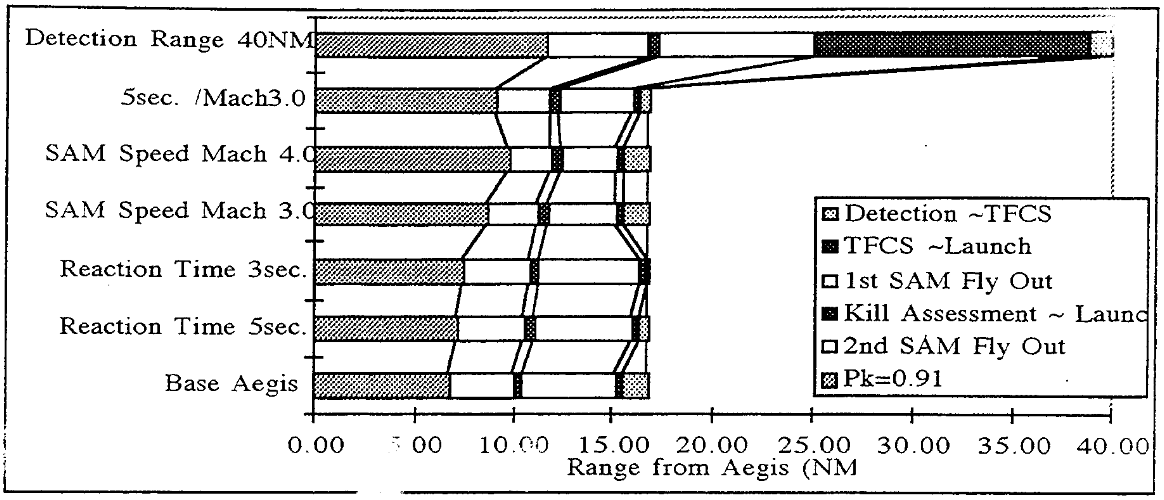

Fig. 17. Improvement Alternatives and Sequential Events (Range): Mach 0.9 ASCM

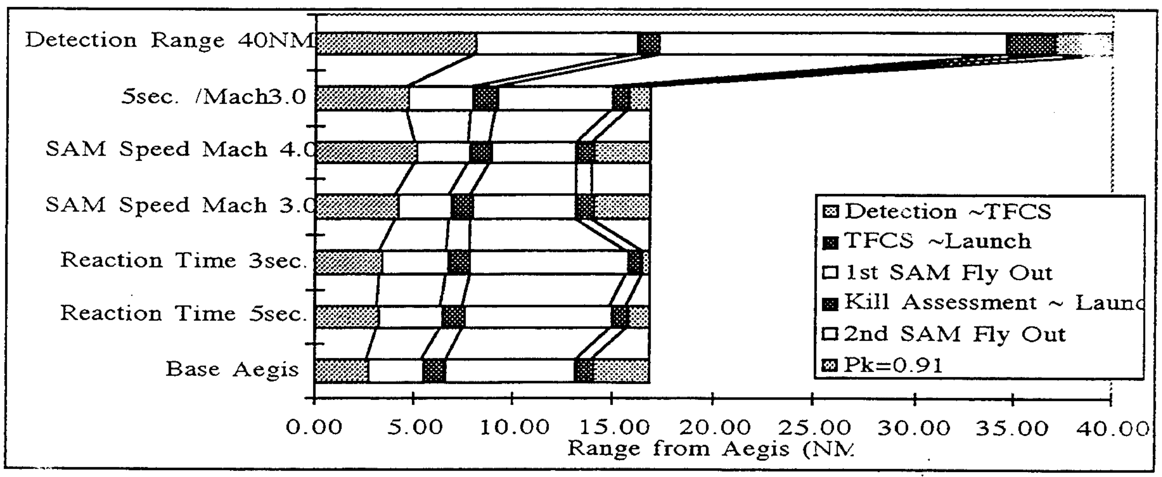

Fig. 18. Improvement Alternatives and Sequential Events (Range): Mach 2.0 ASCM

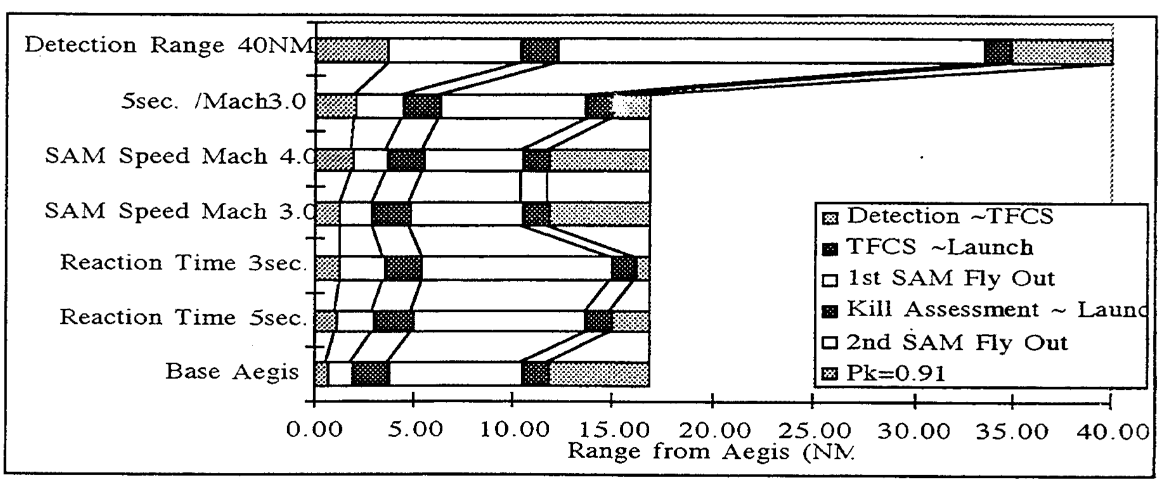

Fig. 19. Improvement Alternatives and Sequential Events (Range): Mach 3.5 ASCM

2. Reducing Variability of Initial Detection Range ~ Crystal Ball

Figures 20 and 22 show the assumption of probability density functions of initial detection range. These are not based on any data but are assumed distributions to show the effect of variability. The results of 100 trials of Monte Carlo Simulation by Crystal Ball are shown in Figures 21 and 23. Examining the two results shows sensitivity of detection range is very important. The effort of reducing the variability of detection range is crucial.

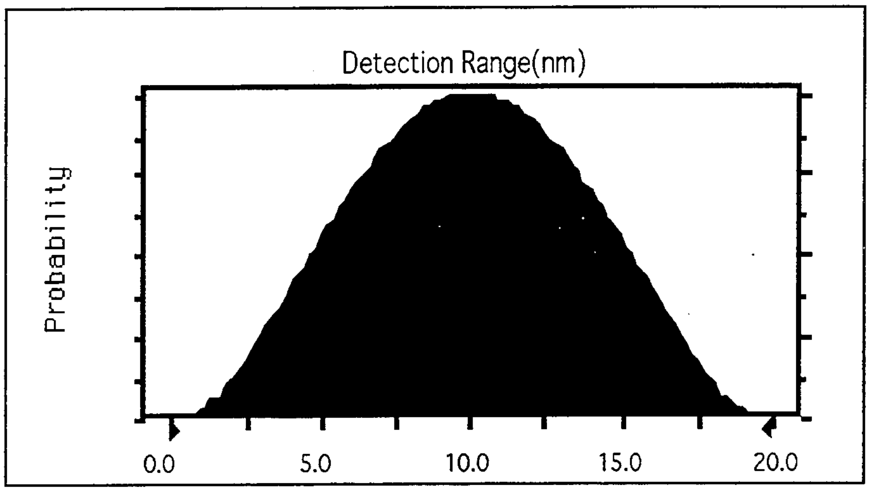

Fig. 20. Assumption of Detection Range pdf (1)

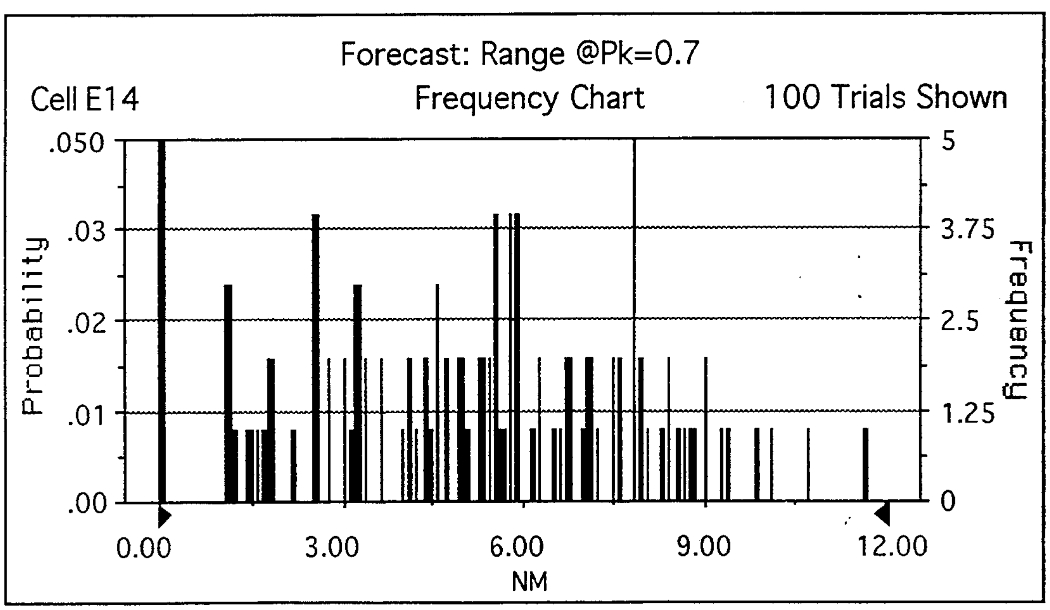

Fig. 21. Intercept Range Forecast (1)

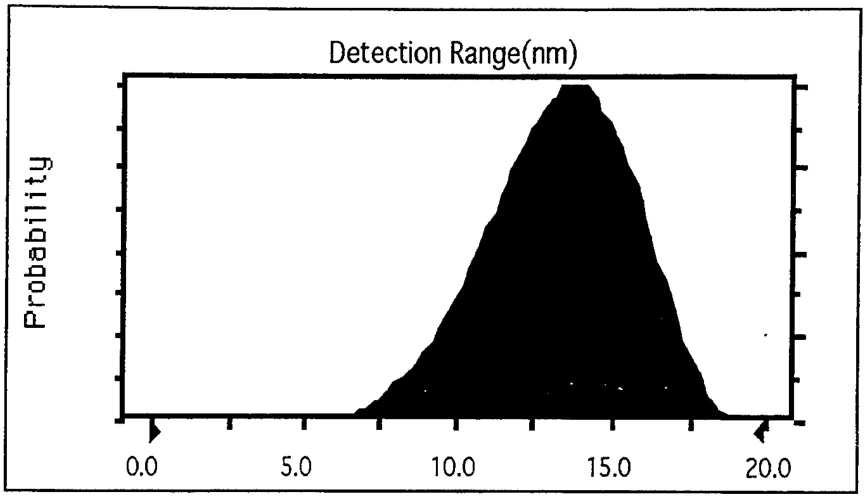

Fig. 22. Assumption of Detection Range pdf (2)

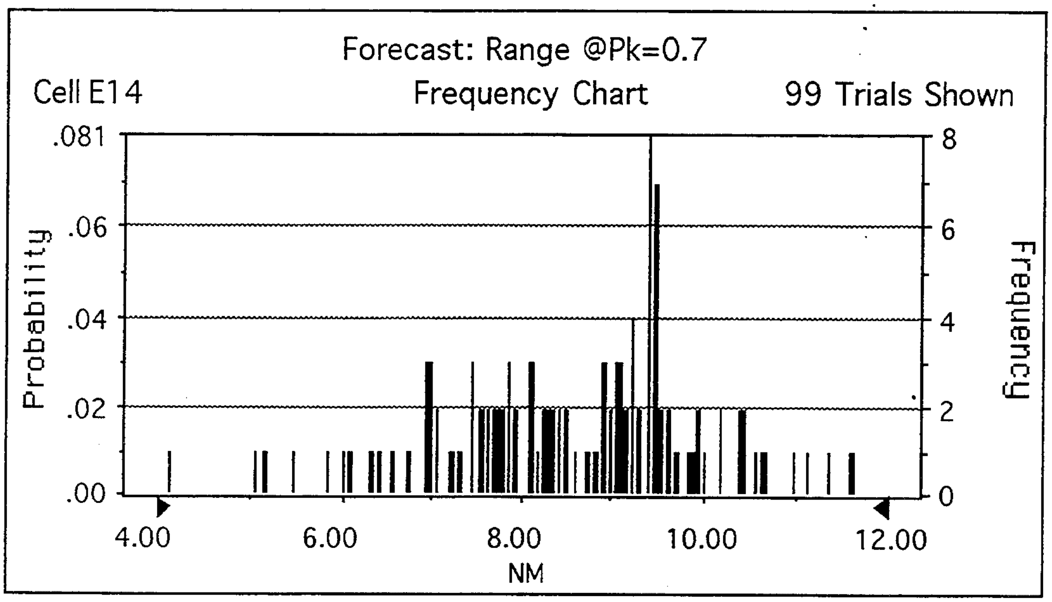

Fig. 23. Intercept Range Forecast (2)

3. FSU Self-Defense Capability ~ Monte Carlo Simulation Spread Sheet

Table 5 shows the result of 100 trials of each case.

	Attack Ratio = 1.0		Attack Ratio = 0.5	
FSU Self-Defense Capability	Probability of Mission Success	Average SAM Consumption	Probability of Mission Success	Average SAM Consumption
0.0	0.4	8.7	0.48	10.1
0.5	0.66	10.8	0.7	11.3

Table 5. Results of Monte Carlo Simulation Spread Sheet

This results shows clearly that if continuous ASCM attacks are predicted during a mission, it is difficult for Aegis to guarantee the FSU protection particularly one without any self-defense. In other words, to keep a certain level of acceptable mission risk in a multi-ASCM attack, the requirement of total lethality level becomes very high. Therefore, it could be dangerous to rely only on the Aegis air defense weapon system. Furthermore, it could be technically easy and cost less to install a point defense system on an FSU instead of improving the Aegis area defense lethality.

B. SUMMARY

The above results are summarized as follows:

1) Emerging supersonic sea-skimmers would obsolete the effort of reducing time delay and increasing SAM speed.
2) Expanding the sensor envelope could be most effective course of action.
3) Reducing variability of target detection range is important. It could be accomplished using multi-sensors.
4) A high level of lethality is required to eliminate the continuous ASCM attack.
5) A self-defense weapon system on the FSU is desirable.

V. RECOMMENDING AAW ASSETS FOR JMSDF

As seen in the previous Chapter, the expansion of the detection sensor envelop is an essential factor for improving Aegis lethality against ASCMs in the view of "a denial area". The next step is to identify the alternatives of AAW assets to be considered. To determine the set of possible solutions, *DoD Instruction 5000.2-M* [Ref. 33] suggests:

> When structuring the set of alternatives, consider both current systems and improved version, along with systems in development by the other Services or Allies and conceptual systems not yet on the drawing board.

continuing:

> A frequent weakness in an analysis results from developing inadequate attention to potential modifications of existing systems.

A. EXTERNAL SENSORS

The upgrade of SPY-1D, called SPY-1E, was announced and is "intended for greater effectiveness against sea-skimmers." [Ref. 16: p.338] It may be effective in the adverse environments, such as sea clutter and multipath effects, however, it cannot overcome the radar horizon limitation. Adding to that, a single radar dependent system would have deficiencies:

> A single source or sensor is unlikely , within the foreseeable future, to provide sufficient reliable identification for an engagement to be made. The combination of inputs from <u>different sensor types at several locations</u> to form a recognized air picture (RAP) does, however, allow the allegiance of a particular track - friendly, enemy or neutral - to be determined with a high level of confidence. [Ref. 25: p. 335]

> future anti-air detection and tracking systems will probably be optical and passive in nature and significantly more jamresistant. [Ref. 9: p. 48]

These statements imply that using multi-sensors, especially passive sensors, and increasing the number of sensor platforms are desirable. There are four types of sensor platforms: a surface (ground or ship) base, an air base, underwater (submarine) base and a space (satellite) base. In terms of AAW, the air base system, commonly called airborne early warning (AEW), and satellite base system look attractive since they could expand the sensor envelope dramatically. However, introducing a satellite for Japanese Self Defense Force (JDSF) is a topic beyond the AAW tactical improvement of JMSDF. Therefore, this option will be put aside.

Now, it may be worthwhile to extend the study into the TBMD. Pitts studied the contribution of Aegis to the TBMD in his master thesis. [Ref. 35] He concluded:

> the two most critical items needed to make Aegis an effective, flexible and mobile ballistic missile defense platform are <u>external sources of cueing</u> and a

> warhead and missile with proper guidance and control that can defeat all future ballistic missile threats.[Ref. 35: p. 81]

The importance of external cueing sources are to minimize the degradation of AAW missions caused by adding the TBMD mission. The cause of the degradation is explained:

> Because of the ballistic missile's extremely high speed and high trajectory, the energy required in upgrades to direct the radar to higher altitudes and to search a large space volume in a ballistic missile defense mode is very significant. Detection and tracking also requires more energy because of the complicated geometry of the problem. While the Aegis is in a ballistic missile defense mode, significant degradations are made to its other AAW missions. [Ref. 35: p. 79]

The reason that the external cueing sources are effective is that they provide early warning about the target to the Aegis.

> If the cue were sufficiently accurate, the Aegis would only have to look into limited search volume to acquire the target. The benefit of the cue would be in minimizing the time it takes the AN/SPY-1 to acquire the target. This would allow for earlier engagement and minimize the impact of its ballistic missile defense mission on overall AAW mission. [Ref. 35: p. 69]

Expanding the sensor envelope by using external platforms is also desirable for TBMD. Although his recommendation is to use a satellite as a external source, there is room for other AEW type platforms.

Another important expected function of Aegis is as an intelligence center of the battle group. In other words, the Aegis plays a role on gathering and providing a real-time battle field situational awareness. This is based on the high performance of the Aegis system:

> The display system can also store up to 40 patterns, such as formation diagrams, anchorages, and amphibious boat lanes. It can automatically initiate up to 16 simultaneous track histories until ordered to stop doing so. It can provide digital maps of the area in which the ship is operating, refreshing own-ship position every 2.5 sec.
> Aegis as a whole is credited with the ability to handle 128 tracks. The SPY-1 radar can actually handle more, the extra capacity being used to avoid overflow. [Ref. 16: p. 352]

Reportedly, SPY-1 can scan a hemisphere of 175 NM radius. [Ref. 16: p. 338] It is very powerful, especially in an open ocean. However, because of the lack of external sensors, the JMSDF Aegis cannot use this capability in a littoral area.

From the above discussion, it is reasonable to consider an AEW platforms as a external sensor for the JMSDF Aegis. Furthermore, introducing an airborne asset to the JMSDF Aegis would open some courses of SAM improvements since it could also be used as a relay point of guidance commands between SAM and launched ship or an illuminator

platform for terminal guidance, and so on. Although the idea of using AEW as an "eye" of the fleet is not new, the potential of new types of platforms are recently in the limelight:

> Airborne early warning is already important, but improvements in the missiles may make it attractive to build balloons or long-endurance, unmanned air vehicle borne radars merely to detect and track missiles before they appear over a ship's horizon. [Ref. 29, p43]

There are three categories of AEW alternatives from the view of maritime operations without a carrier: a shipboard AEW helicopter, an unmanned air vehicle (UAV), and an airship.

B. AEW SHIPBOARD HELICOPTER

A shipboard helicopter is now an indespensable asset for the ASW mission. JMSDF has eight SH-60Js in each flotilla. However, an AEW version of shipboard helicopter is not adopted widely. The reason is probably that most countries assume their missions are always under cover of long-range shore-based aircraft, such as AWACS. It is a considerable issue, however, because it was the same reason that the Royal Navy rejected the Thorn-EMI's proposal of an AEW adaptation of Searchwater before the Falklands War. [Ref. 16: p. 143] Once this war happened, the Royal Navy ordered Sea King AEW and has operated it since then. Therefore, the limitation of AWACS operation has to be considered carefully by starting a study of suitable AEW platform alternatives for future maritime operations. The result of a maritime operation of Sea King is impressive:

> According to the Fleet Air Arm helicopter AEW has brought new flexibility to naval operations. Searchwater's ability to 'profile' targets and its low-level detection gives a task force commander more information than he had before. For example Searchwater's excellent definition enables it to detect a sea-skimming missile at 45nm, a crucial advance in anti-missile defense. The reconnaissance role of the helicopter at sea is expanding rapidly, with ESM also providing passive detection of missiles at considerable range, back up by active jamming. [Ref. 36: p. 74]

On the other hand:

> Some critics doubt that shipboard helicopters will be allowed to fly around the battle zone, illuminating targets and relaying data back to parent ships, arguing that the triple problems of Command, Control and Communication will ensure that all helicopters are 'confined to hangers' as soon as battle is imminent. [Ref. 36: p. 73]

However, the article continues:

> Against that, it is beyond dispute that crisis-management in a time of tension would be impossible without helicopters to reconnoiter and keep potential adversaries under surveillance. [Ref. 36: p. 73]

Table 6 shows the characteristics of a current version of Sea King AEW and USSR Helix-B which may have same mission role. According to Jane's All The Worlds Aircraft, Sea King AEW. Mk7 was proposed. It would be installed as a new radar (Searchwater 2000 competitive GEC-Marconi Blue Vixen variant) and include JTIDS new data central system with color display . The service entry would be in 2000. [Ref. 37]

	Sea King AEW Mk 2A	Helix-B (Radar Picket Ka-31)
operational Speed (kt)	132	135
Service Ceiling (feet)	4000	14100
Endurance on Station(hr)	2	2.5
Range(NM) (Max. Standard Fuel)	580	248
Surveillance radius(NM)		54-81(fighter size) 135(surface vessels)
Rotor Diameter (feet)	62.0	52.2
Weight Empty (lb)	16163	12170
Max. T/O Weight (lb)	21500	27750
Sensors	Searchwater Radar 'Orange Crop' ESM 'Jubilee Guardsman' IFF IFF MKII and Link16	BigBulge Radar 'Hot Brick' ESM 'Slap Shpt' IFF

Table 6. Ship-borne AEW Helicopter After Ref. [37]

C. UAV

In 1981, Edward Teller told the Association of Unmanned Vehicle Systems that "The unmanned vehicle today is a technology akin to the importance of radar and computers in 1935." [Ref. 38: p. 23] His words suggest that a UAV would be a indispensable technology for future military operation. Actually, the importance of having a UAV capability to support operational missions was stressed by the former President George Bush:

> "As a former Navy TBM (torpedo bomber) combat pilot, I appreciate the benefits to be gained by using unmanned vehicles in high threat areas for reconnaissance, and intelligence collection prior to military action."
> "The limited use to data of unmanned vehicles in Vietnam, the Persian Gulf, and Lebanon has demonstrated their potential in accomplishing a wide range

missions. The work now underway on air, ground, and sea unmanned vehicles for our armed forces represents an opportunity to explore further their offensive and defensive capabilities. Unmanned vehicles have a significant place in our future defense programs." [Ref. 38: p. 25]

UAV technology could be provide a new way of battle field management to a commander. The most significant feature is that it can be used without exposing a human to danger. However, it is still in the developing stages and its operational concept is not clearly defined. There are lots of questions on how to use it. For example, it would be used as an intelligence asset or as a combat asset, in a tactical field or a strategic field. To put it the other way round, it has a great potential on a variety of missions. Therefor, it should be a powerful alternative of JMSDF AAW improvements.

1. Maritime UAV

When designing and/or acquiring a maritime UAV, one must consider the limited deck space on surface combatants for launch and recovery. This indicates the need for a vertical-take-off-and-landing (VTOL) type aircraft. Appendix E lists some of the types of UAVs which are planned or currently being developed. In terms of VTOL technology, the intermeshing rotors are interesting. Two counterrotating main rotor blades work together to increase aircraft lift by providing additional airflow for one another. Thus, an impressive lift-to-weight ratio can be achieved. Reportedly, Multi Mission Intermeshing Rotor Aircraft (MMIRA) demonstrator developed by Kamman Corp. weighs under 4000 lbs. but can carry a 6000-lb payload. It is a manned aircraft for test purposes. However, Kamman Vice President Ken Nasshan said "We can easily scale down the demonstrator's size." on *Armed Force Journal International* in 1992. [Ref. 39]

2. HALE (High-Altitude, Long-Endurance) UAV

Teledyne Ryan's Tier II-plus is a HALE type UAV and one of the major UAV programs in the U.S. The operational characteristics are shown in Table 7. Since the operation of land-base aircraft is restricted by its base, it cannot always help in a maritime operation. However, HALE UAV could overcome this. The reason is in the words of US Navy Capt. Al Hutchins in the Armed Force Journal:

> There will be no ship launch capability for Tier 2-plus, which requires a 5000-foot airship, but considerable effort is being put into ensuring that the aircraft and its payloads are controllable directly from ships, either by

satellite or line-of sight radio link. "with a 3000 nm operating radius for Tier 2-plus, there is no real need to have it on the deck." [Ref. 40: p. 39]

Model	Operation Radius	Maximum Altitude	On-Station Loiter Time	Total Flight Time
Tier II-plus	3000 NM	65000 feet	24 hours	8-10 hours

Table 7. Operational Characteristics of Tier II-plus

Furthermore, HALE UAV has a lot of advantages over satellite and land-base manned aircraft like AWACS. These are summarized in Table 8. From this table, it is obvious that HALE UAVs are also suited for the TBMD mission. Therefore, the HALE UAV should be a worthwhile alternative for JMSDF AAW.

Compared to Satellites	Compared to Manned Aircraft
* Relaxed reliability requirements (comes back periodically for repair)	* Can stay on-station far longer
* Can use far less costly sensors	* Range allows basing option
* Can be updated with new technology	* Air refueling not required
* Can operate from any military airfield	* "Wooden Round" in Peacetime
* Far lower unit cost	* Far lower unit cost
* Continuous coverage in required area	* Far lower operating cost
* Command and control organic to user	* More survival

Table 8. HALE UAV vs. Satellites and Manned Aircraft From [Ref. 41]

D. AIRSHIP

C.E. Myers, Jr's report about an airship, based on his experience in the six-degrees-of-freedom Navy Air ship simulator at NASA's Ames Aeronautical Laboratory in California, describes an airship's attractive potential for maritime operation. His comments could provide a proper way of looking at an airship:

> many viewed the proposed Battle Surveillance Airship as a grotesque, sluggish, and uninteresting flying machine. Others, however, saw it as the world's fastest, most maneuverable ship, which is turning out to be the case.

Considering its lack of susceptibility to mines and torpedoes, it may be the safest of all ships. [Ref. 42: p. 42]

There are two major airship based systems. One is the Maritime Aerostat Tracking and Surveillance system (MATSS), which is the latest and most versatile system offered for sea-based or land-based surveillance of littoral regions. The other is the Low Altitude Surveillance System (LASS) which is intended for long-range detection of small low-flying aircraft. [Ref. 38] MATSS is installed in the TCOM 32M airship and LASS is in TCOM 71M. These characteristics are listed in Table 9.

Name	TCOM32M	TCOM71M
Length (feet)	104.979	232.979
Internal Volume (cu ft)	60035	365000
Max. payload (lb)	882	3527
Structural Weight (lb)	-	5511
Operating Altitude (feet)	2950 (with 882lb payload) 4597 (with 441lb payload)	15090 (with 3527 lb payload)
System	MATSS (Fully coherent I/J band radar can detect 21.5 sq. ft OTH surface or air targets from 2095-3940 ft. altitude)	LASS (an all-solid state D band coherent radar known as E-LASS with a range capability of 173 nm)

Table 9. Characteristics of TCOM Airships After [Ref. 37]

The research on an airship system in maritime operations was done by Shelby. [Ref. 43] In his study, a system is proposed to combine an air ship based fire control system with surface ship launched SAMs (NTU/SM-2 ER), and scenarios are developed for convoy missions in a moderate ASCM threat environment and for surface battle group operations in a high threat (60, closely spaced ASCMs) environment. The results are extracted from his abstract:

1) Using an airship/AAW surface escort based AAW defensive system for convoys will have the requirement for AAW surface escort.
2) In a surface battle group scenario, a combination of airship and older AAW escorts results in, a significant reduction in the total number of AAW escorts

required to counter the ASCM threat, a reduction in the total number of escorts expected to receive damage during a raid, and the attrition of 90% of the attacking aircraft.

3) The cost of obtaining the indicated AAW capability over a 30 year life-cycle is shown to be at least three times lower when using an airship based system compared to using a combination of fixed-wing and helicopters.

These surveys indicate that an airship is worth considering for further study as an alternative to improve the JMSDF AAW capability. The greatest advantages of an airship could be a large payload and long endurance. The small number of required crew, compared to a ship, is also attractive. However, a survivability against anti-air missiles should be examined since an airship is clearly observable and seems to have a large critical area.

E. DESIRABLE AEW

Since AEW helicopters are already in service, introducing these technologies to JMSDF would be the easiest way to upgrade Aegis. If AEW platforms are an emergent need, modifying the existing JMSDF SH-60J ASW helicopters or the MH-53E mine-sweeping helicopters into an AEW version seems to be reasonable. "Unlike unmanned air vehicles (UAV) they are suitable for controlling and enforcing embargo measures (establishing contact, lowering/recovering of boarding party, etc.)." [Ref. 44: p. 36] This operational flexibility is one of the most desirable things in a low intensity conflict. Therefore, adopting a shipboard AEW helicopter as an integral part of JMSDF Aegis should be considered.

Using shipboard helicopters as Aegis assets is also consistent with the U.S. DDG-51 Flight IIA upgrade. However, its objective seems to be mainly a complement of a surface attack mission, and it is also based on the assumption that the air control or the air superiority is established. This assumption implies that a denial area has been already secured by other methods, such as carrier based fighters. This is not the case that we are interested in.

Compared to fixed wing AEWs such as E-2C Howkeyes, the helicopter's capability is limited. It could be difficult to grasp the situational awareness of a wide area. The problem is the limitation of payloads and an operational altitude. Actually the capability of AEW is primarily dependent on installed equipment. It is directly related to the space and payloads of a platform. The ceiling is related to the physical constraints of search area, that

is a radar horizon. If a 100 NM radius of search area is required, the ceiling must be more than 6600 feet to meet the limit of radar horizon. To make bad things worse, usually payloads and ceiling is a trade-off in a helicopter type platform. This is an important point when considering AEW alternatives.

Adding to that, sending pilots into the potentially dangerous zone is controversial issue. Eliminating the risk of casualties as much as possible is urgent:

> Manpower is the single most expensive items in running a navy and the next decade will see increasing pressure on Western navies to reduce manning whilst maintaining an appropriate defensive and offensive capability. [Ref. 45: p. 29]

This quote indicates not only the casualties but also the required personnel to operate a certain system, such as operators, trainers, maintenance people. Actually, saving human resources would be vital in Japan. The Advisory Group on Defense Issue reported:

> In particular, 18-year-olds. who from the core of the eligible population, is expected to drop about 40% 25years from now. Assuming these population changes, we believe it is necessary to consider defense buildup in a direction leading to the conservation of human resources.[Ref. 3; p. 19]

From the view point of saving human resources, an airship and UAV seem to be suitable for JMSDF in the future. They also have a great potential in the tactically changing environments. Therefore, starting the research and development of an UAV and an airship is recommended.

F. SOFT KILL POINT DEFENSE WEAPON (AEGIS AND FSU)

What is verified in the trials of Monte Carlo simulation is that to heavily rely on an area defense system to kill attacking ASCMs is not a good way. If we try to achieve no risk of FSU kill by only using Aegis lethality, the cost should be very high. The reason is that the marginal effectiveness of achieving the high lethality around the edge of its weapon envelope would be much smaller than putting point defense systems on the units to be protected, which is the FSU.

Purely a defensive operation, including the provision of air cover over FSUs, needs a high confidence of IFF. Uncertainty of the situation is increases as the distance from Aegis. Therefore, it could be difficult for Aegis commander to decide launching missiles within the very restricted time, especially if the graduated response is required.

Even if point defense systems are loaded on FSUs, weapons release is bound by strict, often inhibiting, rules of engagement. It could be said that the difficulty of releasing "hard kill" weapons in ambiguous situation is inherent and critical:

> the hard kill solution is risky in hostile environments short of full-scale war. Examples of this include the USS Stark in the Persian Gulf in 1987; to be effective, the area defense SAM system would have had to fire on an Iraqi aircraft before that aircraft fired its anti-ship missile, i.e. before the potentially hostile but outwardly friendly aircraft had confirmed its intention to attack. Another example is the USS Vincennes, which did fire in an apparently hostile Iranian aircraft only to find that it was as innocent civilian airliner.[Ref. 28: p. 59]

One solution is to adopt "soft kill" weapons as point defense system:

> Some naval experts conclude that the predominantly 'hard kill' layered defense system must be augmented by a capable 'soft kill', particularly in the graduated response situations. [Ref. 28: p. 59]

It may be more effective and could cost less:

> Reliance on hard kill is seen in Europe as increasingly expensive and fought with danger, while newer soft kill systems promising in prolonging the combat lives of vessels facing the threat of modern antiship missiles.[Ref. 47: P. 38]

> the Australian Nulka trials achieved over 90 percent kills. .... Nulka cost per round is about 20 percent of the cost of SM-1.[Ref. 28: p. 60]

Considering the speed and sophistication of electronical equipments, the "soft kill" weapons could be obsolete faster than "hard kill" weapons. The effective life time would be short. However, reflecting the increasing importance of graduated response and cost reduction, "soft kill" weapons are recommended. In addition to that, installation of a point defense system on every FSU, including commercial ships going through a dangerous zone, is also recommended.

VI. CONCLUSION AND REMAINING PROBLEMS

The principal aim of this thesis was to understand and model the essential elements of air defense in future JMSDF AAW scenarios by using COEA basis of logic. The initial motive of this study coincides with C.E. Myers, Jr's opinions about the Joint Advanced Strike Technology (JAST):

> JAST is typical of the backward approach, however, which assumes that the aviators can determine the mission after the aircraft is procured. Today, such efforts are much too expensive: the approach, which was "affordable" during the Cold War, is no longer appropriate. Today, new programs demand up-front mission analysis, and conceptual exercise using surrogate equipment - plus simulation and evaluation to define the system function. [Ref. 47: p. 73]

The key of any acquisition program is to identify the appropriate course of action in the early phases. It must answer these questions:

What are the legitimate mission objectives?

Why do we need to pursue them?

What are the alternatives?

Can we adapt existing equipment - if not, what is the character of the equipment we need?

To answer these questions, a measure of effectiveness (MOE) for Aegis AAW was defined for the mission threat analysis in a littoral area operation. It is "a denial area at an acceptable risk". Several alternative improvements to Aegis were studied by using spread sheet models based on this MOE.

A. CONCLUSION

As seen from the results of Chapter IV, expanding the OTH capability, which includes the expansion of both sensors and weapons envelope, is a critical improvement for JMSDF Aegis destroyers. The sensor envelope expansion should have priority over everything since it is a prerequisite for the improvements of other weapon system components. In Chapter V, it was concluded that AEW could be very effective asset for expanding the OTH capability and as a "force multiplier". Adding to that, utilizing the existing SH-60J helicopter as AEW and starting further research of an UAV and an airship were recommended based on subjective examination of JMSDF limited human resources.

From the results of the Monte Carlo simulation, a self-defense system loaded on a FSU is desired and a "soft kill" weapon would be suitable for graduated response situation which will be likely to occur in a littoral area.

B. REMAINING PROBLEMS

The spread sheet models developed here are useful for grasping the essential part of Aegis improvements, even though the models look so simple. However, they cannot deal with multiple ASCM attacks. The saturation scenario and the point defense weapons coordination would be another challenge. When using the spread sheet, the hardest question to answer is how to estimate each PKSS. The assumption of a PKSS that is a constant through the layer is not true. It could be dependent upon a range. Furthermore, the independence of each shot is also a questionable assumption in practice. These desirable modifications require future study.

With regard to this study of Aegis AAW improvement and based on the results of this research, *DoD Instruction 5000.2 -M* indicated:

> Too often, the capabilities hoped for at the "paper stage" of development do not materialize. A healthy degree of skepticism is required in describing the alternatives. [Ref. 33, 8-6]

This implies that next step should be an examination of the technological feasibility and cost aspects of the specific Aegis improvements. The requirements must be feasible technically and also affordable. If a ship is used as a AEW platform, the limited deck space require VTOL aircraft as mentioned above. Adding to that, it should be noticed that an airborne asset is a part of total AAW system.

> In addition to deck space constrains for landing and take-off, consideration must be given to top-side weight and moment. Many combatants are weight/moment critical. This would mandate that there be no new hardware installed above the waterline or additional antennae installations on masts. Existing hardware, and command and control/antenna systems must be utilized for the UAV and data distribution could be similar to that used presently with LAMPS MK III. [Ref. 38: p. 25]

In terms of AEW, the effectiveness of the fusion of airborne and ship borne sensors should be validated:

> A Sea King equipped with Searchwater controls fighters directly (as does the much more powerful E-2C) rather than merely handling target data down to a ship. ... The system currently lacks the air-to-surface data link associated with many earlier AEW aircraft (which did not them selves control fighters); reportedly, Searchwater also suffers from clutter when tracking low-flying air targets. Introduction of a coherent transmitter (as in the related Skymaster surface radar) would help solve the latter problem, as target doppler would be easier to extract. [Ref. 16: p. 143]

Furthermore, "The current aircraft version of the CEC system, at 2,000 lbs., could not fit within the Hawkeye's limited confines." [Ref. 48: p. 36] This implies that the most important concern should be the payload of AEW aircraft. It could be derived from mission requirements and technological feasibility, which include future improvements. Thus, a clear operational concept of when and how it would be used should be defined. What kind and level of operation we can expect for an airborne asset in the total weapon system is the key to the next step. In this context, AEW survivability must be carefully studied since the impact on the total system after losing AEW could be huge.

As the results in Chapter V shown, the dramatic improvement of AAW capability is also depended on developing a missile that reaches the OTH targets. Therefore, another remaining study is how to improve OTH SAM. There seems to be several alternatives. For example, using an airborne asset as a relay point of guidance commands, using another platform's illuminator for terminal guidance, using active homing missile, and missiles carried by AEW etc. are possible. The key is also examining how much PKSS improvement and cost will be expected to develop each alternative.

APPENDIX A. ASCM CHARACTERISTICS

Origin	Missile	Version	Platform	Max Range(nm)	Speed(Mach)	Flight Alt(ft)	Weight(lb)	Warhead (lb)	L(in)	D(in)	Remark
Argentina		MQ-2 Bigura		486				88-154			Armed version of Argentinian copy of Mirach-100 reconnaissance drone
Brazil		Barracuda		37.8							
China	Silkworm	HY-2	S	51	0.9	330	6068	1131	290		Improved version of USSR SS-N-2 Styx
		HY-2A	S		0.9	330					
		HY-2G	S		0.9	98-164					
		HY-4(FL-4)	S,A	81(732)	0.8-0.85	330 -> 230 and dive	4408/3834	1102	290	29.9	
		C601	A	51-54	0.85	330	5378	1131			
	Sardine	C801(HY-5)	S,A	21.6/27	0.9	66-98 ->16-23	1794	364	228.9	14.2	
	Saccade	C802		65.6	0.8-0.9	66-98 ->16-23	1576				
		FL-1(SY-1)				328-984->98		1131			
		FL-2	G	27	0.9		2865	804	236	21.3	
		FL-7		17.3	1.4	164-328	3967		259.8	21.3	
France	Exocet	AM39	H, A	27(low)-38(high)	0.93	98-229->30-49->8.2-26	1444	364	185	13.7	
		MM38	S	22.7	0.93	98-229->30-49->8.2-26	1653	364	205	13.7	
		MM40	S	35	0.93	98-229->30-49->8.2-26	1884	364	228	13.7	
		MM40 BlockII		38		below 30					
		AM39 BloskII									
		ANS	S,A	55(lololo)/110-137	2	high->seaskimming					1993 cancel
	Armat		A	64.8	2		1212.5	330.8			Anti Radiation
German	Kormoron2	AS34	A	55+	0.95			485	173.2	13.6	
Iraq		Faw70		37.8/81/108				1102			Iraq version of SS-N-2C
Israel	Gabriel	I	S	10.8	0.65	328->66->14.9-19.7	882	397	132	12.8	
		II	S	19.4-21.6	0.65	115->56-66->8.2	1102	397	132	13.8	
		III	S	19.4	0.65	4.9/8.2/13.1	1234	331	150	13.4	
		IIIA/S	A	32.4+	0.73		1322	331	152	13.4	
		IV		108	0.85		2116	(331-441)	185	16.9	abondoned
Italy	Otmat	Mk1	S	32(43)	0.9	262->574 dive					
		Mk2	S	54-97(100)	0.9	66					
	Sea Killer/Marte	Mk2	S,A,H	13.5(16?)	1.9	6.5-33		154			Possible mid-cource guidanse from a helicopter(AB212/Sea King)
Japan		ASM-1	A	27	0.9		1344	496	156.8	13.8	
		SSM-1	S	81			1457	496	197	13.8	
		SSM-2	S								
North Korea		HY-2	S	51	0.9/(603)	330	6068	1131	290		Licensed version of Chinese HY-2 Silkworm
Norway	Penguin	Mk1	H	10.8	0.7		741	250	118	11	
		Mk2mod3	S	15	0.8		749	250	117	11	
		Mk3(AGM-119A)	A	21.6+(30)	0.8		771/882	265	126	11	4 trajectory options(max cruise alt., launch alt., 300ft, sea-skimming)F-16A/B
		Mk2mod7(AGM-119B)	H	18	0.8		848	250			USN: LAMPS, KOREA & GREECE:S: SH-2
South Africa	Skorpioen	II									Copy of Israeli Gabriel II
Sweden		Rb 08A		135	0.65?		2645.5	551	224	26.1	Modified version of French CT-20 Target drone
		RBS 15	G,A	37.8/81	0.7-0.9		1318/1719	551	171	19.7	
Taiwan	Hsiung Feng	I(~Gabriel)									
		II(~Harpoon)				16.4-23					

Sources: The Naval Institute Guide to World Naval Weapon System 1991/92 (Naval Institute Press) [Ref. 16]
The Naval Institute Guide to World Naval Weapon System 1994 Upgrade (Naval Institute Press) [Ref. 17]
Cruise Missile Proliferation in the 1990s (The Center for Strategic International Studies) [Ref. 12]
Surface-Based Air Defense System Analysis (Artech House) [Ref. 49]
U.S. Missile Data Book (Data Search Associates) [Ref. 50]

Origin	Missile	Version	Platform	Max Range(nm)	Speed(Mach/(kt))	Flight Alt (ft)	Weight(lb)	Warhead (lb)	L(in)	D(in)	Remark
UK	Sea Skua	CL839	H,S	8+(13.5)	0.93		319.7	66	98.4	7.9	
	Sea Eagle	P3T	A	60+	0.85		1325	500	163	15.8	
	ALARM		A,H	10.8	2		441		1966.9	9	Anti Radiation
USA	Harpoon	RGM-84A-E	A,S	[illegible]	0.85		1151	489	151.2	13.4	120nm range airlaunched version(AGM-84)
	SLAM	AGM-64E	A,S	120					1777	13.4	
	Tomahawk	BGM-109B	S	250	0.7		2700	1000	219.6	20.4	1500nm range land attack version (BGM-109A)
	HARM	AGM-88A-C	A	80(35-55)	2		798	145.5	164.2	10	Anti Radiation
	Hellfire II	AGM-114K	A	4	1		100	20	64.8	7	
	Marveric	AGM-65E/F	A	14			635	300	98	12	
USSR	Styx	SS-N-2A(P-15,4K40,50-Kh)	S	18	0.9		5070	1100	255.6	30	
		SS-N-2B(P-20)	S	18	0.9				255.6	30	Folding wing
		SS-N-2C(P-20K,P-21)	S	45(27-38)	0.9	82-164			255.6	31	(=SS-N-11), P-21 IRversion
		SS-N-2D(P-20M,P-22)	S								
	Starbright	SS-N-7(P-20L)	SS	35	0.9		74440	1100	276	21	
	Shaddock	SS-N-3(P-5, P-7)	S	250	1.4		12592.4	2200	358.3	37.8	OTH shiplaunched anti carrier missile
	Siren	SS-N-9(P-50)	S	58-65	0.8		6509.1	1100	346.5	82.7	
	Sandbox	SS-N-12(P-35)	S	300	2.5		11023.1	2200	460.6	35.4	
	Shipwreck	SS-N-19(P-500)	S	[illegible]			10000		401.6	37.8	Video data link back to the firing ship
	Sunburn	SS-N-22(P-80/P-100)	S	55-68	2.5				370.1	20.5	Succesor to SS-N-9 , It will fit a U.S.Mk41 Launcher
	Harpoonsky	SS-N-25(Kh-35)	S,A	70.2		16.4-32.8	1322.8	319.7	173.2	16.5	Harpoon like missile, Airlaunched version 147.6in long and 1058lb
	Moskit	3M-80(P-270)	S	48.6	2-3.5	23-66	8708	661	369.5	51.2	rocket-ramjet missile announced at the Abu Dhabi military show in1993
	Kelt	AS-5	A		0.9						
	Kingfish	AS-6	A	H:378 L 135	2.5(H),1.2(L)		10582	2205	393.7	35.4	
	Karen	AS-10		6	0.9		882	220	137.8	12	
	Kilter	AS-11	A	30			1719	375	193	16.5	
	kegler	AS-12	A	18			771		150		
	Kingbolt	AS-13(Kh-59A)	A	62.9	0.7-0.83		1929	551	230	16.7	EO guidance (~U.S. SLAM)
	Kedge	AS-14(Kh-29)	A	4					154	15.9	
	Kickback	AS-16	A	54-82	5		2426	331	188	17.9	
		AS-17(Kh-31A)	A	37.8			650	90	266		Kh-31:anti AWACS
		Kh-65(R-55)	A	153	0.48-0.77						
	Yakhont		S,SS	164	2-2.5						New missile announced at the 1993 Paris Air Show(ramjet version of P-80?)
	Alpha		G,S,A,SS		0.67-0.7->2.0		15432.4	441			New missile announced at the 1993 Paris Air Show
	Bastion		G								New missile announced at the 1993 Paris Air Show

Sources:
The Naval Institute Guide to World Naval Weapon System 1991/92 (Naval Instituts Press) [Ref. 16]
The Naval Institute Guide to World Naval Weapon System 1994 Upgrade (Naval Instituts Press) [Ref. 17]
Cruise Missile Proliferation in the 1990s (The Center for Strategic International Studies) [Ref 12]
Surface-Based Air Defense System Analysis (Artsch House) [Ref. 49]
U.S. Missile Data Book (Data Search Associates) [Ref. 50]

APPENDIX B. 2-D SAM FLIGHT PROFILE MODEL

The main purpose of developing a 2-D SAM flight profile model is to find an appropriate SAM average horizontal speed to use as an input value in the 1-D model spread sheet. SM-2/Mk-41 VLS/Aegis system is a highly sophisticated system with several phases of guidance. However, for the average horizontal speed for 1-D model, a simple proportional navigation (PN) guidance scheme is used. Basically, the FORTRAN program of "Two-dimensional tactical missile-target engagement simulation" in [Ref. 51: p. 31] is rewritten in Visual Basic in the macro of Microsoft Excel.

Mathematically, the proportional guidance low can be stated as

$$n_C = N \cdot V_C \cdot \dot{\lambda} \tag{B-1}$$

where n_C is the acceleration command (in ft/s^2), N is a unitless designer chosen gain (usually in the range of 3-5) known as the effective navigation ratio, V_C is the missile-target closing velocity (in ft/s), and λ is the line-of-sight angle (in rad). The overdot indicates the time derivative of the line-of-sight angle or the line-of-sight rate. This program uses the assumption that both the SAM and target travel at a constant velocity. [Ref. 51: p. 26]

The boost phase of the Aegis missile is too complex to simulate in a simple program. Therefore, instead of simulating this phase, the highest position of the SAM in the flight at which the SAM may be flying horizontally, and time from launch to this point are assumed and used as input variables to this PN simulation.

Figures 24, 25, and 26 show the SAM profile against Mach 0.9, 2.0, and 3.5 ASCM with 40 feet altitude. SAM velocity is assumed Mach 2.5 and the PN starting point is a 5000 foot altitude and 1 NM horizontally away from Aegis. The necessary time from launch to the upper point is 5.5 seconds, and the ASCM detection occurs at the radar horizon of 16.9 NM. The reaction time from initial detection to SAM launch is 10 seconds.

The average horizontal speed of each case is summarized Table 10.

ASCM Speed (Mach)	0.9	2.0	3.5
SAM Average Horizontal Speed (Mach)	2.17	2.01	1.68

Table 10. SAM Average Horizontal Speed (PN Simulation)

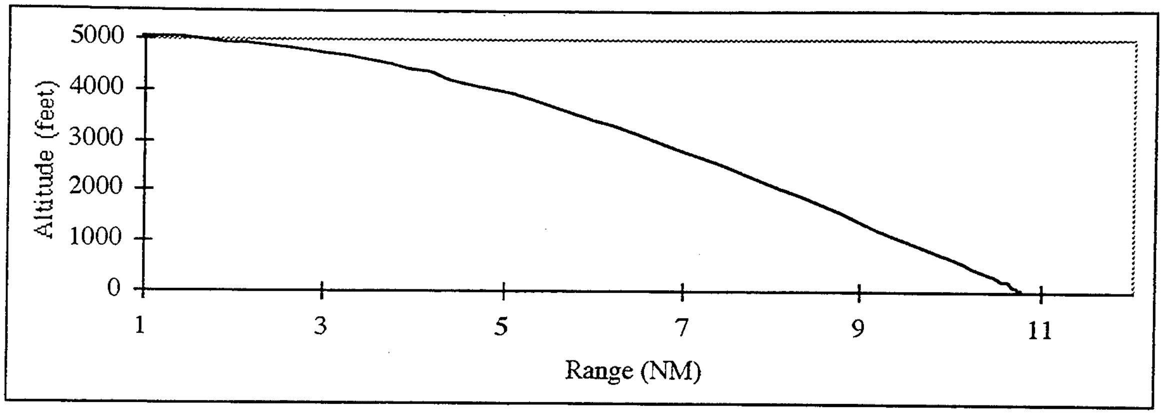

Fig. 24. SAM Flight Profile against Mach 0.9 ASCM

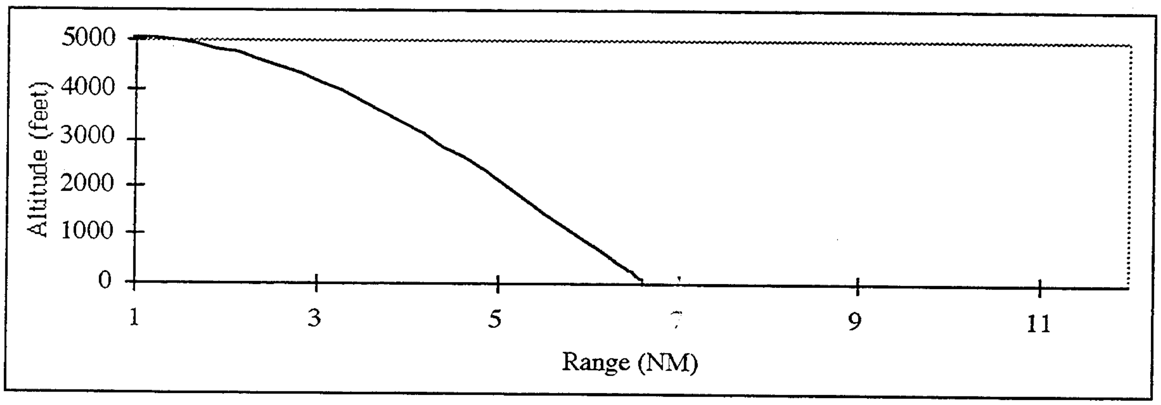

Fig. 25. SAM Flight Profile against Mach 2.0 ASCM

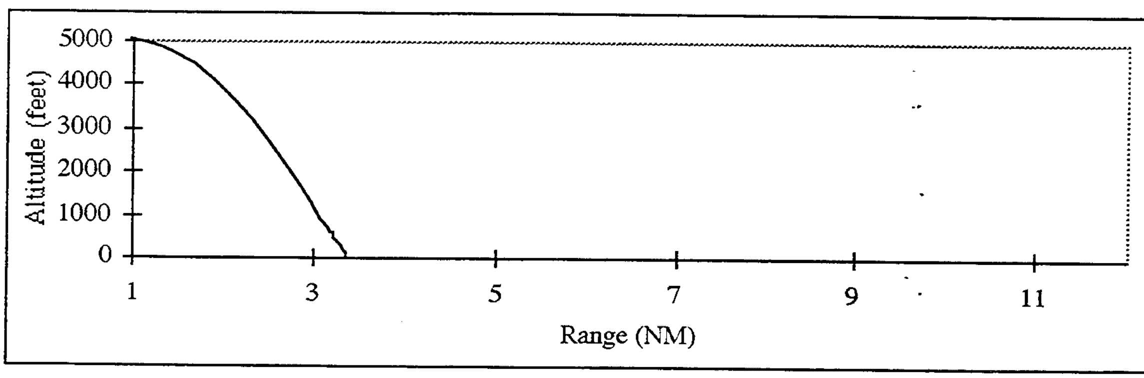

Fig. 26. SAM Flight Profile against Mach 3.5 ASCM

```
***************** PN SIMULATION PROGRAM **************************
Sub PN()
   Columns("H:M").Select
   Selection.ClearContents
Worksheets(1).Cells(1, "H") = "Time(sec)"
Worksheets(1).Cells(1, "I") = "SAM(x)(nm) "
Worksheets(1).Cells(1, "J") = "SAM(z)(nm) "
Worksheets(1).Cells(1, "K") = "Target(x)(nm) "
Worksheets(1).Cells(1, "L") = "Distance(ft) "
Worksheets(1).Cells(1, "M") = "Acc. Comand "

Rtx = Worksheets(1).Cells(4, "C").Value
Rtz = Worksheets(1).Cells(5, "C").Value
Rmx = Worksheets(1).Cells(4, "B").Value
Rmz = Worksheets(1).Cells(5, "B").Value
Vt = Worksheets(1).Cells(7, "C").Value
Vm = Worksheets(1).Cells(7, "B").Value
NR = Worksheets(1).Cells(8, "B").Value
beta = 0
NT = 0

Rtmx = Rtx - Rmx
Rtmz = Rtz - Rmz
RTM = Sqr(Rtmx ^ 2 + Rtmz ^ 2)
LOS = Atn(Rtmz / Rtmx)
X = Vt * Sin(LOS) / Vm
LEAD = Atn(X / Sqr(-X * X + 1))
Pitch = (LOS + LEAD)
HEAD = -Pitch
Vmx = Vm * Cos(Pitch + HEAD)
Vmz = Vm * Sin(Pitch + HEAD)
Vtx = -Vt * Cos(beta)
Vtz = Vt * Sin(beta)
Vtmx = Vtx - Vmx
Vtmz = Vtz - Vmz
VC = -(Rtmx * Vtmx + Rtmz * Vtmz) / RTM
T = 0
Worksheets(1).Cells(2, "H") = T
Worksheets(1).Cells(2, "I") = Rmx / 6076.115
Worksheets(1).Cells(2, "J") = Rmz
Worksheets(1).Cells(2, "K") = Rtx
Worksheets(1).Cells(2, "L") = RTM
i = 3


Do While VC > 0
If RTM > 5000 Then
dt = 1
ElseIf RTM > 3000 Then
dt = 0.1
ElseIf RTM > 1000 Then
dt = 0.01
Else
dt = 0.001
```

```
End If
ORTM = RTM
ORtx = Rtx
ORtz = Rtz
ORmx = Rmx
ORmz = Rmz
OVmx = Vmx
OVmz = Vmz
Obeta = beta
For n = 1 To 2
   Rtmx = Rtx - Rmx
   Rtmz = Rtz - Rmz
   RTM = Sqr(Rtmx ^ 2 + Rtmz ^ 2)
   LOS = Atn(Rtmz / Rtmx)
   Vtmx = Vtx - Vmx
   Vtmz = Vtz - Vmz
   VC = -(Rtmx * Vtmx + Rtmz * Vtmz) / RTM
   LOSD = (Rtmx * Vtmz - Rtmz * Vtmx) / (RTM ^ 2)
   NC = NR * VC * LOSD
   amx = -NC * Sin(LOS)
   amz = NC * Cos(LOS)
   Rmx = Rmx + dt * Vmx
   Rmz = Rmz + dt * Vmz
   Rtx = Rtx + dt * Vtx
   Rtz = Rtz + dt * Vtz
   Vmx = Vmx + dt * amx
   Vmz = Vmz + dt * amz
   Vtx = -Vt * Cos(beta)
   Vtz = Vt * Sin(beta)
   betad = NT / Vt
   beta = beta + betad * dt

Next

T = T + dt
Rtx = 0.5 * (ORtx + Rtx)
Rtz = 0.5 * (ORtz + Rtz)
Rmx = 0.5 * (ORmx + Rmx)
Rmz = 0.5 * (ORmz + Rmz)
Vmx = 0.5 * (OVmx + Vmx)
Vmz = 0.5 * (OVmz + Vmz)
beta = 0.5 * (Obeta + beta)

Worksheets(1).Cells(i, "H") = T
Worksheets(1).Cells(i, "I") = Rmx / 6076.115
Worksheets(1).Cells(i, "J") = Rmz
Worksheets(1).Cells(i, "K") = Rtx
Worksheets(1).Cells(i, "L") = RTM
Worksheets(1).Cells(i, "M") = NC / 32.185


i = i + 1
Loop
Tin = T - dt / 2
```

```
Rin = (Rmx + ORmx) / 2
H = (Rmz + ORmz) / 2
Miss = (RTM + ORTM) / 2
Worksheets(1).Cells(3, "F") = Tin
Worksheets(1).Cells(4, "F") = Rin / 6076.115
Worksheets(1).Cells(5, "F") = H
Worksheets(1).Cells(6, "F") = Miss
 *********************** END PROGRAM ******************************
```

APPENDIX C. EXPECTED VALUE SPREADSHEET AND MACRO PROGRAM

	A	B
3	*Input*	
4	Required Pk	0.900
5	Required Range(nm)	12.0
6		
7	Calculation of Radar Horizon	
8	Radar height(ft)	55.0
9	Incomming Alt.(ft)	40.0
10	Radar Horizon (nm)	16.9
11	ASCM	
12	Speed(Mach)	0.9
13	(->nm)	0.17
14	Effective Detonation(nm)	0.50

Output

		F	G
4	Effective Range(nm)	11.59	11.59
5	Pk @ Required Range	0.70	0.70

Layer	# of shots	
OTH	0	0.00
Long SAM	3	3.00
Short SAM	0	0.00
Gun	1	1.00
Point	1	1.00

1st Intercept Point(nm)	17.30	T.F.C.S. poit (nm)	38.68

	A	B	C	D	E	F
15	Weapon					
16		Propagator		Max Effective		T.F.C.S to Fire Time
17	Layer	Av. Speed(Mach)	(->nm/sec)	Range(nm)	P(KSS)	(sec)
18	OTH	0.0	0.00	0.0	0.70	2.0
19	Long SAM	2.0	0.37	17.3	0.70	2.0
20	Short SAM	0.0	0.00	0.0	0.00	0.0
21	Gun	2.0	0.37	0.0	0.40	5.0
22	Point		0.00	0.0	0.50	3.0

	A	B
23	Sensor & Combat System	
24	Detection Range(nm)	16.9
25	Det. to Fire Control Solution Time Delay (sec)	3.0
26	Kill assesment Time Delay (sec)	1.0

Warning Status: Initial Reaction Time (sec)	5.0

Calculation

	Layer	Propagator Speed(nm/sec)	Max Effective Range(nm)	P(KSS)	T.F.C.S. to Fire Time (sec)	T.F.C.S pt.(nm) for Using Max. Range	Firing pt.(nm) for Intercepting at Min. Range
32	2	0.37	17.3	0.70	2.00	25.42	0.00
33	1	0.00	0.0	0.70	2.00	0.00	-
34	3	0.00	0.0	0.00	0.00	0.00	-
35	4	0.37	0.0	0.40	5.00	0.83	0.00
36	5	0.00	0.0	0.50	3.00	0.00	-

Threat pt.(nm) from Agis @fire	Intercept Time (sec) from firing	Intercept pt.(nm) ferom Aegis	P(KSS)	P(leak)	Cumulative Pk
25.09	47.08	17.30	0.70	0.300000	0.700000
16.80	31.54	11.59	0.70	0.090000	0.910000
11.09	20.82	7.65	0.70	0.027000	0.973000
6.66	12.49	4.59	0.40	0.016200	0.983800
		1.00	0.50	0.008100	0.991900

```
********************** EXPECTED VALUE PROGRAM ******************
Sub AAW()
Application.Run Macro:="Aegis.mod!sim"
Application.Run Macro:="Aegis.mod!effective"
ActiveWindow.SmallScroll Down:=-16
End Sub

Sub sim()
range("F4:F5,E8:E12,I6:L20").Select
   Selection.ClearContents
'*********************************************************
For i = 18 To 22
   Worksheets(1).Cells(i + 14, "A") = i - 17
   For j = 3 To 6
   Worksheets(1).Cells(i + 14, j - 1) = Worksheets(1).Cells(i, j)
   Next j
Next i

   range("A31:E36").Select
   Application.CutCopyMode = False
   Selection.Sort Key1:=range("C31"), Order1:=xlDescending, Header:= _
      xlGuess, OrderCustom:=1, MatchCase:=False, Orientation:=_
      xlTopToBottom
'*********************************************************

Dim W() As Variant
ReDim W(6, 8)
For i = 1 To 6
 For j = 1 To 8
   W(i, j) = Worksheets(1).Cells(i + 31, j).Value
 Next j
 Next i
 'resize
 N = 0
 i = 1
 Do While W(i, 3) <> 0
 N = N + 1
 i = i + 1
 Loop

Vcm = Worksheets(1).Cells(13, "B").Value
DP = Worksheets(1).Cells(14, "B").Value

Rdet = Worksheets(1).Cells(24, "B").Value
dt1 = Worksheets(1).Cells(25, "B").Value
dt2 = Worksheets(1).Cells(26, "B").Value
dti = Worksheets(1).Cells(25, "F").Value
'*********** compleate reading *****************

Rid = Rdet - (dt1 + dti) * Vcm
Worksheets(1).Cells(14, "G") = Rid

For i = 1 To N + 1
  If Rid >= W(i, 6) Then
```

```
      Rid = W(i, 6)
      Rfire = Rid - W(i, 5) * Vcm
      Exit For
   ElseIf Rid >= W(i, 7) + W(i, 5) * Vcm Then
      Rfire = Rid - W(i, 5) * Vcm
      Exit For
   End If
Next i

If DP >= Rfire Then
GoTo death
End If

dt3 = W(i, 5)
Rmin = W(i, 7)
Vsam = W(i, 2)
Pssk = W(i, 4)
wp = 0

If W(i, 1) < 4 Then
   GoSub Fire
ElseIf W(i, 1) = 4 Then
   GoTo Gun
Else
  GoTo Point
End If

If Rint <= DP Then
GoTo death
End If

Do While W(i + 1, 1) < 4
   If Rid >= W(i + 1, 6) Then
      Rid = W(i + 1, 6)
      Rfire = Rid - W(i + 1, 5) * Vcm
   ElseIf Rid - W(i + 1, 5) * Vcm > W(i + 1, 7) Then
      Rfire = Rid - W(i + 1, 5) * Vcm
   Else
   i = i + 1
   GoTo xx
   End If
      i = i + 1
      dt3 = W(i, 5)
      Rmin = W(i, 7)
      Vsam = W(i, 2)
      Pssk = W(i, 4)
   GoSub Fire
xx:
Loop
   If Rint >= W(i + 1, 6) Then
      Rid = W(i + 1, 6)
      Rfire = Rid - W(i + 1, 5) * Vcm
   ElseIf Rid - W(i + 1, 5) * Vcm > W(i + 1, 7) Then
      Rfire = Rid - W(i + 1, 5) * Vcm
```

```
    End If
    i = i + 1
    If W(i, 1) = 4 Then
      Vsam = W(i, 2)
      Pssk = W(i, 4)
    GoTo Gun
    Else
      Pssk = W(i, 4)
    GoTo Point
    End If
Exit Sub
'************** Start Subroutine Fire *****************
Fire:
   shot = 0
   Do While Rfire >= Rmin
      Tint = Rfire / (Vcm + Vsam)
      Rint = Vsam * Tint
   If Rint <= DP Then
   Exit Do
   End If
      Worksheets(1).Cells(wp + shot + 6, "I") = Rfire
      Worksheets(1).Cells(wp + shot + 6, "J") = Tint
      Worksheets(1).Cells(wp + shot + 6, "K") = Rint
      Worksheets(1).Cells(wp + shot + 6, "L") = Pssk

      shot = shot + 1
      Rid = Rint - dt2 * Vcm
      Rfire = Rid - dt3 * Vcm
   Loop
   Worksheets(1).Cells(W(i, 1) + 7, "E") = shot
   wp = wp + shot
Return
'*****************************************************
Gun:
      Tint = Rfire / (Vcm + Vsam)
      Rint = Vsam * Tint

      If Rint <= DP Then
      i = i + 1
      Pssk = W(i, 4)
      GoTo Point
      End If


      Worksheets(1).Cells(wp + 6, "I") = Rfire
      Worksheets(1).Cells(wp + 6, "J") = Tint
      Worksheets(1).Cells(wp + 6, "K") = Rint
      Worksheets(1).Cells(wp + 6, "L") = Pssk
      Worksheets(1).Cells(W(i, 1) + 7, "E") = 1

      i = i + 1
      Pssk = W(i, 4)
      wp = wp + 1
Point:
```

```
        If W(i, 3) <= DP Then
        GoTo death
        End If

        Worksheets(1).Cells(wp + 6, "K") = W(i, 3)
        Worksheets(1).Cells(wp + 6, "L") = W(i, 4)
        Worksheets(1).Cells(W(i, 1) + 7, "E") = 1

death:
End Sub

Sub effective()
RPK = Worksheets(1).Cells(4, "B").Value
PK = Worksheets(1).Cells(6, "N").Value
Count = 0
Do While RPK >= PK
If Count = 15 Then
Exit Do
End If
Count = Count + 1
PK = Worksheets(1).Cells(6 + Count, "N").Value
Loop
Worksheets(1).Cells(4, "F") = Worksheets(1).Cells(6 + Count, "K").Value
nono:

RR = Worksheets(1).Cells(5, "B").Value
ER = Worksheets(1).Cells(6, "K").Value
If RR < ER Then
   Count = 0
   Do While RR < ER
   Count = Count + 1
   ER = Worksheets(1).Cells(6 + Count, "K").Value
   Loop
   Worksheets(1).Cells(5, "F") = Worksheets(1).Cells(5 + Count, "N").Value
Else
  Worksheets(1).Cells(5, "F") = 0
End If
End Sub

   ********************** END PROGRAM ******************************
```

APPENDIX D. MONTE CARLO SIMULATION SPREAD SHEET AND MACRO PROGRAM

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2	Number of attacks	10			Mission Fail Counter	180						
3	Ratio of FSU attack	1			Mission Success Counter	120						
4	Trial	300			Suvibability of FSU	0.4000						
5					Current Status							
6	Layer	# of shots	Cumulative	Quantity limit	Current Trial	300		Target pt.(nm) from Agis @fire	Intercept Time (sec) from firing	Intercept pt.(nm) from Aegis	Intercept State	Weapon ID
7	OTH		0		Current attack	10						
8	long SAM (Rh)	1	12	30	This attack is against	FSU		15.2	28.6	10.5	hit	2
9	short SAM		0	0								
10	Gun		0	30	Current Aegis Status							
11	Point		0	30	Current FSU Status	No Damage						
12	Aegis damaged counter		0	1								
13	HVU damaged counter		0	1	Previous Trial Mission	Mission Success						
14	Shot down pt.(nm) by Aegis	10.5										
15	Calculation of Radar Horizon											
16	Radar Height(ft)	55.0		ASCM								
17	ASCM Incomming Alt.(ft)	40.0		Speed(Mach)		0.9						
18	Radar Horizon (nm)	16.9		(>nm)		0.1656						
19	Aegis			Effective Detonation(nm)		0.5						
20	Warning Status: Initial Reaction Time(sec)	5										
21	Sensor & Combat System			FSU								
22	Detection Range(nm)	16.9		Position from Aegis (nm)		5.0						
23	Det. to Target Solution Time Delay (sec)	3.0		Expected ability of self defense		0						
24	Kill Assesment Time Delay (sec)	1.0										
25	Weapon							Weapon Consumption	Each Trial	Cumulative	Average	
26		Max effective	Propagator		Target Solution to Fire			OTH	0	0	0.0	
27	Layer(ID)	Range(nm)	Av. Speed(Mach)	P(KSS)	Time Delay(sec)			Long SAM	12	2602	8.7	
28	OTH(1)	0.0	0	0.00	0.0			Short SAM	0	0	0.0	
29	Long SAM (2)	17.3	2	0.70	2.0			Gun	0	0	0.0	
30	Short SAM(3)	0.0	0	0.00	0.0			CIWS	0	0	0.0	
31	Gun(4)	4.5	2	0.40	5.0							
32	CIWS(5)	1.0	0	0.50	2.0							
33												
34			Max effective	Propagator		T.F.C.S. to Fire	T.F.C.S. pt.(nm) for	Firing pt.(nm) for				
35		Layer ID	Range(nm)	Av. Speed(Mach)	P(KSS)	Time Delay(sec)	Using Max. Range	Intercepting at Min. Range				
36		2	17.3	2	0.70	2.00	25.42	6.53				
37		4	4.5	2	0.40	5.00	7.35	1.45				
38		5	1.0	0	0.50	2.00	0.00					
39		1	0.0	0	0.00	0.00	0.00					
40		3	0.0	0	0.00	0.00	0.00					

```
'*************Monte Carlo Simulation Program ********************
Sub AAWsim()
   Sheets("Sheet1").Select                          'Clear previous run results
   Range("B7:B14,C7:C13,H8:L22,I26:J30,F2:F4,B36:F40,F6:F13").Select
   Selection.ClearContents
   Sheets("Sheet2").Select                          'Sheet2 : data for shot down point chart
   Columns("F:F").Select
   Selection.ClearContents
   Sheets("Sheet1").Select
'Copy inputed weapon chracteristics to bottom tables

   For K = 28 To 32
     Worksheets(1).Cells(K + 8, "B") = K - 27
     For l = 2 To 5
     Worksheets(1).Cells(K + 8, l + 1) = Worksheets(1).Cells(K, l).Value
     Next l
   Next K

'Sort by using "weapon max range" descendingly to eliminate not carrying weponary
'If range=0, which means no weapon, put down to the bottom row

   Range("B35:F40").Sort Key1:=Range("C35"), Order1:=xlDescending, Header:= _
     xlGuess, OrderCustom:=1, MatchCase:=False, Orientation:= _
     xlTopToBottom
'~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
   attack = Worksheets(1).Cells(2, "B").Value     'Expected number of attacks during the
mission
   FSU = Worksheets(1).Cells(3, "B").Value    'The likelihood of attacking HVU (not Aegis)
   trial = Worksheets(1).Cells(4, "B").Value      'Number of trial(=run)
   counter = 0
   countattack = 0
   SC = 0                 'mission success counter
   FC = 0                 'mission fail counter
Do While counter < trial

   'Clear previous trial results
   Range("B7:C13,I26:I30,F8:F11").Select
   Selection.ClearContents
    Worksheets(1).Cells(6, "F") = counter + 1      'Show current trial number

'^^^^^^^^^^^^^^^^^^^^^^ program for each attack ^^^^^^^^^^^^^^^^^^^^^^^^
Do While countattack < attack

  ' Condition of acceptable damage of FSU(=mission success criterion)
  If Worksheets(1).Cells(13, "C").Value = Worksheets(1).Cells(13, "D").Value Then
  Exit Do
  End If

   'Clrear previous attack results
     Range("B7:B13,H8:L22").Select
     Selection.ClearContents
     Worksheets(1).Cells(7, "F") = countattack + 1 'Show current attack number

     'Check current Aegis status
     If Worksheets(1).Cells(10, "F") = "Mulfunction/Sunk" Then
     Ap = 2
     Else
     Ap = Rnd            'Rnd :random number (0~1)
```

```
      End If

      'AP represents hostile intention. If Aegis is sunk , all threat will attack FSU
      'If Aegis work, threat is split based on the attack ratio.

      If Ap <= FSU Then
      Worksheets(1).Cells(8, "F") = "FSU"
      Application.Run Macro:="AegisFSU!cover"    'main program : attack against FSU
      ElseIf Ap <= 1 Then
      Worksheets(1).Cells(8, "F") = "Aegis"
      Application.Run Macro:="AegisFSU!shoot"    'main program : attack against Aegis
      Else
      Worksheets(1).Cells(8, "F") = "FSU"
      Application.Run Macro:="AegisFSU!self"      'main program : after Aegis sunk
      End If
      Application.Run Macro:="AegisFSU!shotdown"  'picke out shot down range from Aegis
      Application.Run Macro:="AegisFSU!pointind"  'make histogram of shot down point
      countattack = countattack + 1
  Loop

'^^^^^^^^^^^^^^^^^^^^^^return and do next attack^^^^^^^^^^^^^^^^^^^^^^^^^^
'Check FSU status (FC:mission failure counter, SC: mission success counter)

    If countattack < attack Then
      Worksheets(1).Cells(11, "F") = "Mulfunction/Sunk"
      FC = 1
      Worksheets(1).Cells(13, "F") = "Mission Fail"
    ElseIf Worksheets(1).Cells(13, "C").Value = 0 Then
      Worksheets(1).Cells(11, "F") = "No Damage"
      SC = 1
      Worksheets(1).Cells(13, "F") = "Mission Success"
    ElseIf Worksheets(1).Cells(13, "C").Value < Worksheets(1).Cells(13, "D").Value Then
      Worksheets(1).Cells(11, "F") = "Parcial Damage"
      SC = 1
      Worksheets(1).Cells(13, "F") = "Mission Success"
    Else
      Worksheets(1).Cells(11, "F") = "Mulfunction/Sunk"
      FC = 1
      Worksheets(1).Cells(13, "F") = "Mission Fail"
    End If

'Output the number of mission success and fail to caliculate the probability of mission success

    countattack = 0
    counter = counter + 1
    Worksheets(1).Cells(2, "F") = Worksheets(1).Cells(2, "F") + FC
    Worksheets(1).Cells(3, "F") = Worksheets(1).Cells(3, "F") + SC
    Worksheets(1).Cells(4, "F") = Worksheets(1).Cells(3, "F") / counter
    SC = 0
    FC = 0
    'Cumulate weapon comsumption to calculate average weapon consumption during the
mission
    For s = 7 To 11
    Worksheets(1).Cells(s + 19, "I") = Worksheets(1).Cells(s, "C")
    Worksheets(1).Cells(s + 19, "J") = Worksheets(1).Cells(s + 19, "J") + Worksheets(1).Cells(s
+ 19, "I")
    Next
Loop
```

```
End Sub
'**********************************************************

'************* START MAIN PROGRAM (attack against Aegis) ******
Sub shoot()

'Read Weapon Characters from the spreadsheet and put them into matrix W(i,j)
Dim W() As Variant
ReDim W(6, 10)                                   'For program tech. W(6,j) are always "0"
For i = 1 To 6
 For j = 1 To 8
   W(i, j) = Worksheets(1).Cells(i + 35, j + 1).Value
 Next j
 Next i

For i = 1 To 5
   W(i, 9) = Worksheets(1).Cells(W(i, 1) + 6, 3).Value      'Read consumed weapon quantity
   W(i, 10) = Worksheets(1).Cells(W(i, 1) + 6, 4).Value    'Read initially carried weapon
quantity(=limit)
Next i

'Make sure how many layers(weapons) we have
'(When max range=0, no more layer exist) e.g.N=4 we have four defence layer
 N = 0
 i = 1
 Do While W(i, 2) <> 0            ' cf. W(6,2) is always 0
 N = N + 1
 i = i + 1
 Loop

'Read Threat Characters

Vcm = Worksheets(1).Cells(18, "F").Value        'ASCM incomming speed
DP = Worksheets(1).Cells(19, "F").Value         'If ASCM penetrates within DP, Aegis would
                                                'be damaged.

'Read Sensor & Combat system capability

Rdet = Worksheets(1).Cells(22, "B").Value       'Initial detection point
dt1 = Worksheets(1).Cells(23, "B").Value        'Delay time from detection to identification
                                                 'depend on sensor, combat system and
environment
dt2 = Worksheets(1).Cells(24, "B").Value        'Kill assesment delay time
dti = Worksheets(1).Cells(20, "B").Value        ' Initial reaction delay time (readiness)

'~~~~~~~~~~~~~~~~~~~~~~~ Compleate Reading ~~~~~~~~~~~~~~~~~~~~~~~

'Calculate Identification Point
Rid = Rdet - (dt1 + dti) * Vcm
'Find Starting weapon
                                 ' "i" indicates layer (i=1 is the most outer layer available)
For i = 1 To N
  If Rid > W(i, 6) Then
     Rid = W(i, 6)    'If Aegis track threat far enough to use max weapon range, wait and fire.
     Rfire = Rid - W(i, 5) * Vcm
     Exit For
  ElseIf Rid > W(i, 7) + W(i, 5) * Vcm Then
```

```
      Rfire = Rid - W(i, 5) * Vcm   'If threat is already within the weapon reachable range,
      Exit For                       'Immediately fire.
   End If
Next i                 'Finnaly "i" indicates the starting layer counted from the most outer layer.

If DP >= Rfire Then        'The case of Aegis can't find an ASCM until it hit.
End If

NM = 1116.45 / 6076.115                  'constant: transform "Mach->nm/sec"

'The 1st shooting weapon characters
dt3 = W(i, 5)              'Refiring time delay (launcher)
Rmin = W(i, 7)       'Rmin is assumed to be equal to the next layer weapon max. range
Vsam = W(i, 3) * NM        'Outgoing average horizontal speed
Pkss = W(i, 4)             'Single shot probability of kill
Consum = W(i, 9)           'number of consumed weapon
Limit = W(i, 10)           'number of initially carried weapon
wp = 0

'Choose weapon subroutine depend on Layer ID

If W(i, 1) < 4 Then  '(Layer ID) <4 means weapon is SAM then Go to "fire" subroutine
   GoSub SAM          '         =4 means weapon is Gun, then skip to "Gun"
ElseIf W(i, 1) = 4 Then  '      >4(actually=5) means weapon is point defence, skip to "CIWS"
   GoTo Gun
Else
  GoTo CIWS
End If

'~~~~~~~~~~~~~~~~~~ Returning line from subroutine "SAM" ~~~~~~~~~~~~~~~~~~~
If Rint <= DP Then          'If SAM missed and ASCM is within DP, Aegis must be damaged
GoTo death                    ' Then go to death.(also this trial should be terminated)
ElseIf H = "hit" Then       'H represents the event states - "hit" or "miss"
GoTo hit                     'If hit, trial should be treminated. Skip to "hit"(=end).
End If
'Find next layer initial firing point based on next layer(i+1) weapon (i.e.SAM, Gun, or CIWS).

Do While W(i + 1, 1) < 4                  'SAM case
   If Rid >= W(i + 1, 6) Then
      Rid = W(i + 1, 6)
      Rfire = Rid - W(i + 1, 5) * Vcm
   ElseIf Rid - W(i + 1, 5) * Vcm > W(i + 1, 7) Then
      Rfire = Rid - W(i + 1, 5) * Vcm
   Else
   i = i + 1
   GoTo xxx
   End If
      i = i + 1
      dt3 = W(i, 5)
      Rmin = W(i, 7)
      Vsam = W(i, 3) * NM        'Input variables for subroutine"SAM"-Rmin,Vsam, Pssk,
      Pkss = W(i, 4)              'and number of consumed and initially carried weapon
      Consum = W(i, 9)
      Limit = W(i, 10)
   GoSub SAM
'  ~~~~~~~~~~~~~~~~~ returning line from subroutine "SAM" ~~~~~~~~~~~
   If Rint <= DP Then
   GoTo death
```

```
   ElseIf H = "hit" Then
   GoTo hit                                   'Status C'K
   End If
xxx:
Loop
'~~~~~~~~~~~~~~~~~~~ End of SAM loop ~~~~~~~~~~~~~~~~~~~~~~~~~~~

   If Rid >= W(i + 1, 6) Then
      Rid = W(i + 1, 6)
      Rfire = Rid - W(i + 1, 5) * Vcm
   ElseIf Rid - W(i + 1, 5) * Vcm > W(i + 1, 7) Then
      Rfire = Rid - W(i + 1, 5) * Vcm
   End If
      i = i + 1
   If W(i, 1) = 4 Then                      'GUN Case
      Vsam = W(i, 3) * NM
      Pkss = W(i, 4)
      Consum = W(i, 9)
      Limit = W(i, 10)
   GoTo Gun
   Else                                      'CIWS Case
      Pkss = W(i, 4)
      Consum = W(i, 9)
      Limit = W(i, 10)
   GoTo CIWS
   End If
Exit Sub

'****************** Start Subroutine "SAM" ******************
SAM:
   shot = 0
 'Continue to fire until the firing point (intercept +time delay) is less  than
 ' required range where it can intercept within minimum range(=next weapon max range)

   Do While Rfire > Rmin
   If W(i, 9) >= W(i, 10) Then    'C'K remaining weapon quantity.
   Rint = Rid
   Exit Do                         'If nothing remains then use next layer weapon.
   End If

      Tint = Rfire / (Vcm + Vsam)
      Rint = Vsam * Tint
   If Rint <= DP Then              'If intercept point is within DP, then Aegis must get damage.
    Exit Do                        'Exit Do loop and subroutine and then go to "death".
   End If
      Worksheets(1).Cells(wp + shot + 8, "H") = Rfire  'ASCM point from Aegis @SAM fire
      Worksheets(1).Cells(wp + shot + 8, "I") = Tint 'Required time from launch to intercept
      Worksheets(1).Cells(wp + shot + 8, "J") = Rint    'Intercept point from Aegis
      Worksheets(1).Cells(wp + shot + 8, "L") = W(i, 1) 'weapon layer ID

      shot = shot + 1                  'Counting shots
     W(i, 9) = W(i, 9) + 1
      Rid = Rint - dt2 * Vcm           ' Kill assesment time delay ("look" time)
      Rfire = Rid - dt3 * Vcm          ' Next firing point

         '^^^^^^^^^^^^^^^ simulate intercept (shot down or miss) ^^^^^^^^^^^^^^^^
                                              'Rnd:random number generater 0~1
      If Rnd <= Pkss Then                    'Compear given Pkss, determin "hit" or "miss"
```

```
        Worksheets(1).Cells(wp + shot + 7, "K") = "hit"
        H = Worksheets(1).Cells(wp + shot + 7, "K")
        Exit Do                                   'If hit, trial should be terminated.
        Else                                      'Then exit Do loop,  subroutine, and skip to "hit"
        Worksheets(1).Cells(wp + shot + 7, "K") = "miss"   'If miss, continue to shoot
        End If
            '^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
    Loop
    Worksheets(1).Cells(W(i, 1) + 6, "B") = shot      'number of shots done within the layer
    wp = wp + shot
Return
'*********************************************************************************
Gun:                                             'Gun is represented by only one shot for simplicity.
      If W(i, 9) >= W(i, 10) Then                ' C'K remainnig quantity
      i = i + 1
      Pkss = W(i, 4)
      GoTo CIWS
      End If
      Tint = Rfire / (Vcm + Vsam)
      Rint = Vsam * Tint

      If Rint <= DP Then
      i = i + 1
      Pkss = W(i, 4)
      GoTo CIWS
      End If

      Worksheets(1).Cells(wp + 8, "H") = Rfire
      Worksheets(1).Cells(wp + 8, "I") = Tint
      Worksheets(1).Cells(wp + 8, "J") = Rint
      Worksheets(1).Cells(wp + 8, "L") = W(i, 1)
      Worksheets(1).Cells(W(i, 1) + 6, "B") = 1

         '^^^^^^^^^^^^^^^^^^ simulate  intercept  (gun)^^^^^^^^^^^^^^^^
      Prnd = Rnd
      If Prnd <= Pkss Then
      Worksheets(1).Cells(wp + 8, "K") = "hit"
      GoTo hit
      Else
      Worksheets(1).Cells(wp + 8, "K") = "miss"     'If miss, use CIWS layer weapon
      End If

      If W(i + 1, 2) <= DP Then
      GoTo death
      End If
          '^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
      i = i + 1
      Pkss = W(i, 4)
      wp = wp + 1

'*********************************************************************************
CIWS:
      If W(i, 9) >= W(i, 10) Then                 'C'K remaining quantity
      GoTo death
      End If

      If W(i, 2) <= DP Then
      GoTo death
```

```
        End If

        Worksheets(1).Cells(wp + 8, "J") = W(i, 2)
        Worksheets(1).Cells(wp + 8, "L") = W(i, 1)
        Worksheets(1).Cells(W(i, 1) + 6, "B") = 1

        Prnd = Rnd
        If Prnd <= Pkss Then
        Worksheets(1).Cells(wp + 8, "K") = "hit"
        GoTo hit
        End If
        Worksheets(1).Cells(wp + 8, "K") = "Aegis damaged"
        GoTo death
'*************************************************************
death:
Worksheets(1).Cells(12, "B") = 1 'To count how many times Aegis got to be damaged
hit:
' cumulate number of shots from the begining(=weapon consumption)
For m = 7 To 13
Worksheets(1).Cells(m, "C") = Worksheets(1).Cells(m, "C") + Worksheets(1).Cells(m, "B")
Next

'Check status
   If Worksheets(1).Cells(12, "C").Value = 0 Then
      Worksheets(1).Cells(10, "F") = "No Damage"
   ElseIf Worksheets(1).Cells(12, "C").Value < Worksheets(1).Cells(12, "D").Value Then
      Worksheets(1).Cells(10, "F") = "Parcial Damage"
   Else
      Worksheets(1).Cells(10, "F") = "Mulfunction/Sunk"
      Exit Sub
   End If

End Sub
'*************************************************************

'*************** MAIN PROGRAM (attack against FSU) ***************
Sub cover()

Dim W() As Variant
ReDim W(6, 10)
For i = 1 To 6
 For j = 1 To 8
   W(i, j) = Worksheets(1).Cells(i + 35, j + 1).Value
 Next j
 Next i

For i = 1 To 5
   W(i, 9) = Worksheets(1).Cells(W(i, 1) + 6, 3).Value
   W(i, 10) = Worksheets(1).Cells(W(i, 1) + 6, 4).Value
Next i

 N = 0
 i = 1
 Do While W(i, 2) <> 0
 N = N + 1
 i = i + 1
 Loop
```

```
'Read Threat Characters

Vcm = Worksheets(1).Cells(18, "F").Value
DP = Worksheets(1).Cells(19, "F").Value

'Read Sensor & Combat system capability

Rdet = Worksheets(1).Cells(22, "B").Value
dt1 = Worksheets(1).Cells(23, "B").Value
dt2 = Worksheets(1).Cells(24, "B").Value
dti = Worksheets(1).Cells(20, "B").Value

'Read FSU position and self-defense capability

 Position = Worksheets(1).Cells(22, "F").Value
 Pkfsu = Worksheets(1).Cells(23, "F").Value


'~~~~~~~~~~~~~~~~~~~~~~~~~ Compleate Reading ~~~~~~~~~~~~~~~~~~~~~~~~~

Rid = Rdet - (dt1 + dti) * Vcm

For i = 1 To N
   If Rid > W(i, 6) Then
      Rid = W(i, 6)
      Rfire = Rid - W(i, 5) * Vcm
      Exit For
   ElseIf Rid > W(i, 7) + W(i, 5) * Vcm Then
      Rfire = Rid - W(i, 5) * Vcm
      Exit For
   End If
Next i

If DP + Position >= Rfire Then
GoTo death
End If

NM = 1116.45 / 6076.115

'The 1st shooting weapon characters
dt3 = W(i, 5)
Rmin = W(i, 7)
Vsam = W(i, 3) * NM
Pssk = W(i, 4)
Consum = W(i, 9)
Limit = W(i, 10)
wp = 0

'Choose subroutine depend on Layer ID
If W(i, 1) < 4 Then
   GoSub FSUSAM
Else
   GoTo death
End If

'~~~~~~~~~~~~~Returning line from subroutine "FSUSAM"~~~~~~~~~~~~~~~~~~

If Rint <= DP + Position Then
```

```
    GoTo death
 ElseIf H = "hit" Then
    GoTo hit
 End If

 'Only SAM provide air cover over FSU

 Do While W(i + 1, 1) < 4
    If Rid >= W(i + 1, 6) Then
       Rid = W(i + 1, 6)
       Rfire = Rid - W(i + 1, 5) * Vcm
    ElseIf Rid - W(i + 1, 5) * Vcm > W(i + 1, 7) Then
       Rfire = Rid - W(i + 1, 5) * Vcm
    Else
      i = i + 1
      GoTo xx
    End If
       i = i + 1
       dt3 = W(i, 5)
       Rmin = W(i, 7)
       Vsam = W(i, 3) * NM
       Pkss = W(i, 4)
    GoSub FSUSAM
'   ~~~~~~~~~~~~~~~~~ returning line from subroutine "FSUSAM" ~~~~~~~~~~~~~~~~~
    If Rint <= DP + Position Then
    GoTo death
    ElseIf H = "hit" Then
    GoTo hit                                  'Status C'K
    End If
xx:
Loop
    GoTo death
Exit Sub

'*******************Start   Subroutine   FSUSAM****************
FSUSAM:
   shot = 0
   Do While Rfire > Rmin
   If W(i, 9) >= W(i, 10) Then    'C'K remaining weapon quantity.
   Rint = Rid
   Exit Do
   End If

      Tint = Rfire / (Vcm + Vsam)
      Rint = Vsam * Tint
   If Rint <= DP + Position Then    'If intercept point is within DP+Position, then FSU must
get damage.
   Exit Do                           'Exit Do loop and exit subroutine and then go to death.
   End If

     Worksheets(1).Cells(wp + shot + 8, "H") = Rfire
     Worksheets(1).Cells(wp + shot + 8, "I") = Tint
     Worksheets(1).Cells(wp + shot + 8, "J") = Rint
     Worksheets(1).Cells(wp + shot + 8, "L") = W(i, 1)

     shot = shot + 1
     W(i, 9) = W(i, 9) + 1
     Rid = Rint - dt2 * Vcm
```

```
    Rfire = Rid - dt3 * Vcm

        '^^^^^^^^^^^^^^^ simulate intercept (shot down or miss) ^^^^^^^^^^^^^^^^
        Prnd = Rnd                          'Prnd:randum number 0~1
        If Prnd <= Pssk Then                'Compear given Pssk, determin "hit" or "miss"
        Worksheets(1).Cells(wp + shot + 7, "K") = "hit"
        H = Worksheets(1).Cells(wp + shot + 7, "K")
        Exit Do                             'If hit, trial should be terminated.
        Else                                'Then exit Do loop, subroutine, and skip to "hit"
        Worksheets(1).Cells(wp + shot + 7, "K") = "miss"   'If miss, continue to shoot
        End If
          '^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
  Loop
  Worksheets(1).Cells(W(i, 1) + 6, "B") = shot
  wp = wp + shot
Return
'***************************************************************

death:
P = Rnd
If P <= Pkfsu Then
  Worksheets(1).Cells(wp + 8, "K") = "FSU Suvival"
Else
  Worksheets(1).Cells(wp + 8, "K") = "FSU damaged"
  Worksheets(1).Cells(13, "B") = 1
End If
hit:
 For m = 7 To 13
  Worksheets(1).Cells(m, "C") = Worksheets(1).Cells(m, "C") + Worksheets(1).Cells(m, "B")
Next
  If Worksheets(1).Cells(13, "C").Value = 0 Then
    Worksheets(1).Cells(11, "F") = "No Damage"
  ElseIf Worksheets(1).Cells(13, "C").Value < Worksheets(1).Cells(13, "D").Value Then
    Worksheets(1).Cells(11, "F") = "Parcial Damage"
  Else
    Worksheets(1).Cells(11, "F") = "Mulfunction/Sunk"
    Exit Sub
  End If
End Sub
'***************************************************************

'************ MAIN PROGRAM(after Aegis sunk) ********************
Sub self()
Pkfsu = Worksheets(1).Cells(23, "F").Value
P = Rnd
If P <= Pkhvu Then
  Worksheets(1).Cells(8, "K") = "FSU Suvival"
Else
  Worksheets(1).Cells(8, "K") = "FSU damaged"
  Worksheets(1).Cells(13, "B") = 1
End If
 For m = 7 To 13
Worksheets(1).Cells(m, "C") = Worksheets(1).Cells(m, "C") + Worksheets(1).Cells(m, "B")
Next
  If Worksheets(1).Cells(13, "C").Value = 0 Then
    Worksheets(1).Cells(11, "F") = "No Damage"
  ElseIf Worksheets(1).Cells(13, "C").Value < Worksheets(1).Cells(13, "D").Value Then
    Worksheets(1).Cells(11, "F") = "Parcial Damage"
```

```
   Else
      Worksheets(1).Cells(11, "F") = "Mulfunction/Sunk"
   End If

End Sub

'******************* END MAIN PROGRAM ********************

'**********Looking for "hit" in the output to find shot down range ***********
Sub shotdown()
PK = Worksheets(1).Cells(8, "K")
For Count = 0 To 15
PK = Worksheets(1).Cells(8 + Count, "K")
If PK <> "miss" Then
Exit For
End If
Next
If PK = "hit" Then
Worksheets(1).Cells(14, "B") = Worksheets(1).Cells(8 + Count, "J").Value
Else
Worksheets(1).Cells(14, "B") = 0
End If
End Sub

'************* Making histogram of shot down point *********************
Sub pointind()

Worksheets(2).Cells(1, "A") = Worksheets(1).Cells(14, "B").Value
   For o = 1 To 101
Worksheets(2).Cells(o, "F") = Worksheets(2).Cells(o, "F") + Worksheets(2).Cells(o, "E").Value
   Next
End Sub

'********************* END PROGRAM *************************
```

APPENDIX E. VTOL UAV

Name	Canadair CL-227 Sentinel	Daimler-Benz Arerospace Seamons	Deadalus Research STF-9A/B
Country	U.S.A	German	U.S.A
Speed (kt)	70	90 max	100 max
Ceiling (feet)	10000	N/A	20000
Endurance (hour)	4	4.5	6
Weight (lb)	510	1474	742
Propulsion	turboshaft	turboshaft	rotary piston engine
Guidance	INS, remote control	INS, pre-programed	INS/GPS, pre-programed or remote control
Payloads	realtime TV/FLIR	Doppler radar	realtime TV/FLIR
Name	**Sikorsky Cypher**	**Technology Management RPG**	**Freewing Aerial Robotics Tilt-body**
Country	U.S.A	Sweden	France
Speed (kt)	75 cruise	65	150 max
Ceiling (feet)	8200	N/A	10000
Endurance (hour)	3	2.5	3
Weight (lbs)	362	94	461
Propulsion	rotary piston engine	piston engine	piston engine
Guidance	INS/GPS, pre-programed or remote control	GPS, pre-programed or remote control	INS/GPS, pre-programed or remote control
Payloads	realtime TV/FLIR/EW/ communications	realtime TV/FLIR	realtime TV/FLIR/EW

Table 11. VTOL UAV From [Ref. 52]

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